INHALATION THERAPY AND RESUSCITATION

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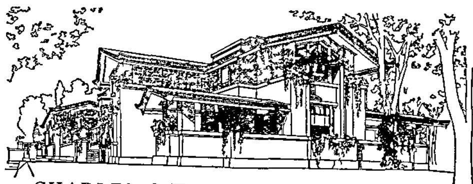
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INHALATION THERAPY AND RESUSCITATION

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To the memory of

Sumner

PREFACE

DISEASE and the hazards of living injure or kill because of oxygen deprivation. Tissue, in the final analysis, ceases to function because of its inability to obtain or to utilize oxygen. Physiologists have long known that the human economy will rapidly deteriorate if deprived of oxygen, for the reserve store of this vital substance is small and anaerobic metabolism cannot make up the deficit. Recent studies have clarified the specific effect of oxygen paucity on bodily tissue and functions. The complete interdependence of systems for their proper functioning can be shown, for when one vital function of the body is damaged by depriving it of its quota of oxygen, other systems soon fail. The bodily response to oxygen deprivation is in large fashion dependent upon the mechanism by which it is produced. A classification based upon etiological circumstances is needed and is herewith submitted.

The inhalation of oxygen enriched atmosphere will in only some circumstances prevent or ameliorate the effects of oxygen want. Satisfactory results with inhalation therapy are therefore dependent upon its use in indicated conditions. An appreciation for the indications for this mode of therapy can be obtained only from an understanding of the specific alteration of function produced by the various forms of hypoxia.

Oxygen deprivation is often associated with carbon dioxide retention. This latter substance in excess may so interfere with vital functions as to cause death. Inhalation of oxygen will not correct carbon dioxide accumulation. It may indeed be the means by which carbon dioxide may be further increased and coma be precipitated. Proper ventilation alone will correct the disturbed physiology and the means to do this needs elaboration.

It is necessary that the proper equipment be employed to accomplish the desired result. No single piece of apparatus has universal application. Some forms of equipment have specific indications and should be so limited. Some, because of improper

design, should not be employed Within the past few years new equipment has been described older apparatus have been restudied and evaluated Submission of such information at this time seems desirable

Breathing of high oxygen atmospheres is not completely free from hazard The altered intrapulmonary pressures produced by some forms of inhalation therapy apparatus result in disturbed circulatory and respiratory states which are harmful Cognizance of these by effects is necessary to prevent further injury to a patient already ill from disease or trauma

Inhalation therapy is a valuable indispensable adjunct to modern medical therapeutics and its use should be encouraged In desiring to stimulate and extend the use of this mode of therapy I have endeavored to collect in a single book much of what I have found is necessary for me to understand it It is my hope that the material herein contained will enable others to recognize the need for this therapeutic endeavor to the end that inhalation therapy will assume its proper sphere of usefulness

M S

ACKNOWLEDGMENTS

IN WRITING this book I have been constantly conscious of the fact that very many people have been both directly and indirectly responsible for much of the material herein contained

The original stimulus for the collection of information in regard to hypoxia was a presentation on this subject before the New England Society of Anesthesiologists on April 2 1949 at the Rhode Island Hospital In this endeavor my brother, Dr Elihu Saklad and Drs Priscilla Sellman William C Howrie Jr and Cecil J Metcalf participated as did Drs Margaret Messinger and Alvin E Gaary Residents in Anesthesia at the time The labor of compilation and writing was of necessity time consuming and I am especially indebted to my associates Drs Elihu Saklad Priscilla Sellman and William C Howrie Jr for the relief from clinical duties which they provided

An early interest in inhalation therapy is the result of my association with Dr Alex M Burgess To him I am grateful for his encouragement and suggestions Dr Hebbel E Hoff in an early reading of the manuscript prevented me from making the same error so many had done before me in crediting John Mayow with discoveries for which he is not truly entitled I am further grateful to Dr Hoff for the information he gave me in regard to the work of Ingenhousz and Fontana Dr Wilfred Pickles kindly read the manuscript and brought to my attention many of my inadequacies in the use of the English language

I wish to acknowledge my gratefulness to Dr John Adriani who suggested I write this book for his confidence in me My thankfulness to Miss Avis K Bearse my secretary for her tireless efforts for it was she who spared me many laborious details I am appreciative of the valued cooperation of Mr Burton Staugaard Director of the Department of Photography of the Rhode Island Hospital

INHALATION THERAPY AND RESUSCITATION

CHAPTER I

HISTORY

The story of the endeavor to fathom the mystery of respiration is a fascinating one The early observers had limited their studies to a consideration of the ventilatory aspect of respiration The fact that ventilation subserves the needs of tissue could not have been determined until it had been shown that blood circulates The specific agent removed from the air and utilized in metabolism could not have been studied until such a substance was isolated The growth of knowledge was not always clear nor constantly progressive for not only did advancing knowledge depend upon earlier discovery but on occasion a wrong theory not only impeded definite progress but in fact reversed it for a time

Up to the time of Harvey respiration had been considered a mechanism for keeping the body cool Aristotle (384–322 B C) had observed in probably the first recorded scientific experiment in respiratory physiology that animals in air tight boxes soon died The correct interpretation escaped him for he wrongly ascribed the death of the animals thus enclosed to their inability to cool themselves Galen (131–201 A D) believed that the object of ventilation was to cool the fiery heart and to introduce air to get rid of the heart s smoky vapors Leonardo da Vinci (1452–1519) recognized that fire consumed something in air and that animals could not live in an atmosphere which could not support a flame The effects of deprivation of air were shown by Vesalius (1514–1564) In 1542 he recorded the experiment of passing a reed into the *Aspera Arteria* of an animal whose thorax had been opened and blowing into it intermittently He found that this caused the lungs to expand and the heart to recover its normal pulsation He also noted that if the lungs were allowed to remain collapsed, the pulsation of the heart and arteries became wavelike ant like and worm like It is to his remarkable powers of observation that we

cites another passage which he says is a remarkable forecast concerning the nature of mountain sickness wherein Boyle discussed air which is too much dilated and is not serviceable for the ends of respiration He compares it to the air in the exhausted chamber which caused a hasty death of animals enclosed therein Because of these studies, Boyle believed that if a man were at a high altitude he would suffer from lack of air Boyle goes on to speak of a Josephus Acosta who relates his own experience in the high mountains of Peru, where he and his companions suffered from the high altitude and were not relieved until they came to a lower level

Boyle s book *New Experiments, Touching the Relation Betwixt Flame and Air*, reveals that he was aware of the fact that respiration and combustion depended upon the presence in air of some specific substance which was removed by either process It is because of this work that Fulton states it is clear that Boyle approached the discovery of oxygen more closely than anyone before Priestley and Lavoisier

In his book *Suspicions about Some Hidden Qualities in the Air* published in 1674 Boyle reports studies on combustion which led him to believe that there is something in the air more important than has as yet been ascribed to it and he suspects that there is in air some substance necessary to combustion

Hooke had been an assistant to Boyle until 1662 He found that a continuous supply of fresh air passed into or through the lungs would maintain life even though the lungs themselves did not move On October 24 1667 Robert Hooke in an experiment before the Royal Society of London records I did heretofore give this Illustrious Society an account of an Experiment I formerly tryed of keeping a Dog alive after his Thorax was all display d by the cutting away of the Ribs and Diaphragme and after the Pericardium of the heart was also taken off the Dog being kept alive by the Reciprocal blowing up of his Lungs with Bellowes and they suffered to subside for the space of an hour or more after his Thorax had been so display d and his Aspera Arteria cut off just below the Epiglotis and bound on upon the nose of the Bellows

In the second experiment by Robert Hooke the surface of the lungs was pricked by a sharp pen knife and by the use of a second

are indebted for so early a description of what we have since come to understand as ventricular fibrillation

Harvey s discovery of the circulation threw no positive light on the physiology of breathing, but did demonstrate that arterial blood is changed to venous in the lungs Though Harvey announced his discovery of the circulation in 1615 and published his book in 1628, no further progress was made until the time of Boyle

Robert Boyle his assistant Robert Hooke and his student Richard Lower are responsible for a revival of interest in respiration and it was they who laid the groundwork for the great progress made in the eighteenth century A contemporary John Mayow has been credited with many of the discoveries of the period A study by Patterson (294) reveals that Mayow in his published works contributed little new but summarized well the views of his contemporaries concerning respiration

Boyle with the assistance of Hooke, constructed an air pump Experiments conducted with it led to the publication by Boyle of his first book entitled *The Spring and Weight of the Air* in 1660 In this book Boyle describes the generation of air from the action of aqua fortis on iron filings Studies conducted by him showed that birds and mice died within thirty seconds to a minute of the time that air is removed from the container by means of a pump If the air is not sucked out, but the container sealed tight the animal would live from thirty to forty minutes It is here that Boyle remarks Perhaps there is some use of the Air which we do not yet so well understand, that makes it so continually needful to the Life of Animals *Paracelsus* (1493–1541) indeed tells us *That as the Stomach concocts Meat, and makes part of it useful to the Body, rejecting the other part, so the Lungs consume part of the Air, and proscribes the rest* So that according to our Hermetick Philosopher we may suppose that there is in the Air a little vital Quintessence which serves to the refreshment and resaturation of our vital Spirits, for which use the grosser and incomparably greater part of the Air being unserviceable it need not seem strange that an Animal stands in need of almost incessantly drawing in fresh Air But though this opinion is not absur d it should not be barely asserted but explicated and prov d It is also from this book, that Fulton (161)

lime is heated it gains phlogiston and that when quicklime is slaked it loses phlogiston Black exploded the phlogiston theory by showing in reality that quickened lime loses something and quicklime when slaked gains something He also noted that a gas fixed air given off by quickened lime and alkalis is also present in expired air, and that this gas is physiologically irrespirable Black determined also that this 'fixed air is given off by the lungs

Priestley discovered oxygen in 1774 He learned that plants could convert vitiated atmosphere which had proven fatal to animals in a manner which would again render it respirable and capable of supporting life In 1779 Ingenhousz had shown that it is only the green portion of the plants which could accomplish this conversion, and in so doing plants take up carbon dioxide and give off oxygen Priestley thus had the truth in his grasp but being a confirmed believer of the phlogiston theory, he explained the facts of respiration in reverse order by believing respiration as the phlogistication of dephlogisticated air

Lavoisier (1743–1794) began his career when the phlogiston theory of Stahl was universally recognized and at first he too was in accord His studies led him to doubt and finally to demonstrate the incorrectness of the Stahlian theory Lavoisier, in possession of the studies of Priestley and Black showed that animal respiration is a process by which oxygen combines with other constituents in the body to form carbon dioxide and water He determined that the generation of heat was the result of the process of combustion going on in the body With Laplace he showed that carbon dioxide produced by respiration is nearly equivalent to the oxygen consumed Lavoisier however had adopted the erroneous theory that the oxidation of carbon takes place in the tubules of the lungs In 1791 this was corrected by Lagrange who discovered that the dissolved oxygen takes up carbon and hydrogen from the tissues as the blood courses through them

In 1837 it was shown by Magnus that venous and arterial blood both contain oxygen as well as carbon dioxide The fact of tissue respiration was demonstrated in this fashion Magnus extracted oxygen and carbon dioxide from the blood and he inferred therefrom that these gases are simply dissolved in it Liebeg pointed out

pair of bellows connected to the first a constant stream of air was delivered keeping the lungs full and without motion He writes there being a continual blast of air forc d into the Lungs by the first pair of Bellows supplying it as it could find its way quite through the Coat of the Lungs by the small holes pricked in it as was said before This being continued for a pretty while the dog as I expected lay still as before, his eyes being all the time very quick and his Heart beating very regularly But upon ceas ing the blast and suffering the Lungs to fall and lye still the Dog would immediately fall into Dying Convulsive fits but he as soon revived again by the renewing the fulness of his Lungs with the constant blast of fresh air He concludes So it was not the sub siding or movelesness of the Lungs that was the immediate cause of Death or the stopping of the circulation of the Blood through the Lungs, but the want of a sufficient supply of fresh air

In 1668 Hooke postulated that dark blood becomes florid in passing through the lungs because it mixes with air Richard Lower and Thomas Willis had noted the difference in color in arterial and venous blood in 1658 In 1669 Lower injected dark venous blood into the insufflated lungs and concluded that the consequent bright color was due to the fact that it had absorbed some of the air passing through the lungs Lower thus made one of the greatest discoveries of medicine that is that blood in passing through the lungs changes in color by deriving some quality from the air This quality he termed ' the nitro aerial spirit

Further progress was not made until the eighteenth century A good deal of the reason why progress was not more readily made *was because of the phlogiston theory Stahl (1660–1734) affirmed* that heat matter was part of all combustible materials and would appear when such bodies were burned This matter he called phlogiston and the portion remaining was dephlogisti cated Because of his fasle theory of combustion the progress of chemistry was delayed for a century although it had been shown experimentally before him that a burning substance gains rather than loses weight

An important physiologic work enabling the completion of the *modern theory of respiration was that of Joseph Black (1728–* 1799) Chemists of his day following Stahl believed that when

showed by alternate closure of the trachea at the end of inspiration and expiration that the mechanism of breathing is automatic and self regulated, the distention and contraction of the lungs being in themselves a normal stimulus of the vagi the effect which Rosen thal had obtained by stimulation of the divided nerve

Heymans and Heymans (217) discovered in 1927 that respiratory reflexes could be elicited from chemoreceptors in the aortic area Further study by Heymans on the role played by the structures at the carotid bifurcation opened a new field in the physiology of respiration Schmidt and Comroe (335) in 1940 stated that the available evidence indicates that the threshold of the chemorecep tors to hypoxia is decidedly less than that of the respiratory centers and that the chemoreceptors are less sensitive to carbon dioxide than the respiratory center They postulated that under certain conditions the control of breathing may be carried out by the chemoreceptors which are responding to deficiency in the oxygen tension of arterial blood rather than to increase in carbon dioxide tension and that under these conditions sudden relief of oxygen deprivation may be followed by cessation of respiration

Paul Bert (64) explained much of what is known about the dis turbed physiology at high altitudes in 1878 He demonstrated that mountain sickness is not due to low barometric pressure but to a decrease in the partial pressure of oxygen He built a chamber wherein he could simulate the decreased barometric pressure of high altitudes He further studied the effects of barometric pres sures greater than at sea level In a series of experiments he laid the foundation of our knowledge of blood gases and the physiology of respiration at abnormal atmospheric pressures

The Italian physiologist Angelo Mosso (277) did not accept Paul Bert s conclusions that the symptoms at high altitude were the result of a decrease in the partial pressure of oxygen He main tained that at high altitudes one breathes so deeply that carbon dioxide is lost with a resulting alkalosis Mosso felt that mountain sickness was due to acapnia a washing out of carbon dioxide rather than to the decrease in the partial pressure of oxygen Paul Bert s reasoning for the symptoms at high altitudes were reaffirmed by experiments conducted by E Rippstein in Kronecker s labora tory (1917) We now know that the symptoms are probably due to

in 1851 that these gases were in loose combination with an unknown substance Hoppe Seyler obtained in crystalline form as hemoglobin these substances with which blood gases are in combination Sir George Gabriel Stokes demonstrated that oxygen could be removed from its combination with hemoglobin by reducing agents

Ingenhousz and Fontana had become interested in gases and realized that an animal can die from lack of oxygen and also from the accumulation of what they knew as fixed air or which we now know as carbon dioxide The importance of the removal of carbon dioxide from rebreathed atmospheres was well known to Fontana He passed exhaled gases over a solution of lime water for the removal of carbon dioxide so as to permit the oxygen to last longer thus becoming the first to use carbon dioxide absorption in the administration of gases for therapeutic purposes Hickman (1827) had observed that the administration of carbon dioxide produces coma and collapse This hazard of carbon dioxide was reaffirmed by Simpson (1856) and Paul Bert (1878)

The role of carbon dioxide as a stimulus to respiration was determined by Miescher in 1885 who showed that a given small increase in carbon dioxide in the inhaled atmosphere results in a marked increase in tidal exchange A corresponding decrease in the oxygen breathed however, produced no such response Haldane engaged in important studies in the chemical regulation of respiration in 1930 He postulated that the H ion concentration of the blood was delicately regulated by means of respiration the kidneys and the liver He considered that respiration did the more *immediate regulation by increasing or decreasing the elimination* of the carbon dioxide and that the kidneys and liver did the long range and more delicate and painstaking work by adjusting fixed alkalis and acids

The neural control of respiration was studied by Legallois in 1811 who showed that if the nervous connections above and below the respiratory center can be successively severed rhythmic discharge of inspiratory and expiratory impulses continue In 1864 Isidor Rosenthal showed that section of both vagi is always followed by deeper slower breathing while the amount of air taken in in unit time is the same as before In 1868 Hering and Breuer

of inhalation therapy until early in the twentieth century In 1907 Sir Arbuthnot Lane advised that oxygen be administered by means of a nasal catheter This method was actively reintroduced by Adrian Stokes in 1916 in the treatment of war casualties Two physiologists Haldane (192) and Meltzer (273), in 1917, observed that favorable results followed the effective administration of oxygen Haldane s oxygen mask was used successfully in cases of pulmonary edema due to war gas poisoning Meltzer treated pneu monia with an oral insufflation apparatus and reported marked improvement in some cases As a result of the beneficial effects of adequate oxygen therapy reported by these two physiologists an impetus was given to the use of oxygen in clinical disease It is interesting to note that Davies and Gilchrist (114) recommended the use of a one way valve system so that the exhaled gases are not rebreathed This was the first attempt to my knowledge to de velop what we now term a demand flow type of apparatus

The principle of mixing gases with room air for dilution pur poses was developed by J S Haldane in the Carbetha apparatus for the administration of carbon dioxide This principle was mod ified and employed in the Poulton Oxygen Tent The principle was reintroduced by Barach in the meter mask Barcroft (45) at about this time devised an oxygen chamber Sir Leonard Hill (218) devised the oxygen tent in 1921

When first employed therapeutically and before the industrial demand for oxygen was apparent oxygen was prepared on a labo ratory scale by heating various oxides and potassium chlorate Oxygen was also produced by electrolysis The volume of oxygen thus produced was small and in purity not always satisfactory In 1895 Carl Von Linde discovered the process of making liquid air by compression and cooling and the production of oxygen by frac tional distillation of liquid air Ninety five per cent of the 5 000 000 000 to 6 000 000 000 cubic feet of oxygen made in this country annually is by this process

the decrease in the partial pressure of oxygen, but Mosso correctly pointed out that acapnia can occur following hyperventilation with a resultant washing out of carbon dioxide It was Yandell Henderson (205) who later paid due attention to Mosso s theory of acapnia

Caisson disease was studied by Sir Leonard Hill in 1912 He reaffirmed the findings of Hoppe Seyler who was the first to observe the appearance of gas in the blood following a sharp and sudden fall of atmospheric pressure

With oxygen isolated and its manufacture made possible it did not take long for interested physicians to employ it in the treatment of disease Oxygen was first given therapeutically by Chaussier (86) in 1780 to dyspneic tuberculous patients and to cyanotic newborn infants Ingenhousz and Fontana were the first to use rubber in a scientific laboratory Ingenhousz in 1781 devised a method for the administration of oxygen In one of his early publications is shown a face mask made of rubber which closely resembles some present day apparatus Thomas Beddoes (1760–1808) had met Lavoisier and this association undoubtedly stimulated him in the use of oxygen in disease In 1798 he established the Pneumatic Institute at Bristol Here were treated all sorts of conditions Oxygen enriched atmospheres were used in the treatment of heart disease asthma opium poisoning ulcers paralysis leprosy and dyspepsia among other conditions His Institute failed One might not agree with the extent of Beddoes indications for inhalation therapy nevertheless many of the conditions he treated respond favorably today to inhalation of high oxygen atmospheres Though he employed oiled silk bags and his technic was perforce inadequate it is important to note that he avoided even though he might not have fully understood the hazard of carbon dioxide accumulation The apparatus that he and James Watt built for inhalation therapy was so constructed that by means of directional valves no rebreathing occurred This principle is carried down to present day respiratory equipment employed in anesthesia resuscitation and in apparatus employed for the determination of basal metabolism

The plan of Beddoes was revived by Louis Waldenburg in 1873 However very little was done to develop more satisfactory methods

tion as a result of the dilation of respiratory bronchioles and alveolar ducts *Mechanical dead space* is the volume of the apparatus into and out of which the patient may be forced to breathe and from which carbon dioxide is not removed effectively

A ALTERATIONS IN RATE

Tachypnea—increased rate of respiration from any cause
Bradypnea—decreased rate of respiration from any cause
Apnea—complete cessation of respiration from whatever cause

Tachypnea and bradypnea are terms which denote alteration in rate only They have no relation to changes in the amounts of respired gases Tachypneic patients may indeed have a greater, or less than normal minute volume exchange A patient with bradypnea may have either a normal, subnormal or increased tidal exchange

B ALTERATIONS IN THE MINUTE VOLUME EXCHANGE OF RESPIRATION

Hyperpnea is an increase in the minute volume exchange from whatever cause It may be the result of an increase in either the rate or depth of respiration or both It may be produced by impulses reaching the respiratory center from the cerebral cortex as in excitement It may also be the result of pain heat or cold An increased demand for oxygen may produce hyperpnea

Hypopnea is a decrease in the minute volume exchange from any cause

Hypercapnea is an increased minute volume exchange due to carbon dioxide excess

Hypocapnea is a decrease in the minute volume exchange due to loss of carbon dioxide

Acapnea is the cessation of respiration due to washing out of carbon dioxide There is hazard in employing this term because a term very much like it *acapnia,* exists in the literature Acapnia denotes an abnormally low tension of carbon dioxide in the blood With hyperpnea in an atmosphere either normal or low in carbon dioxide it is possible to wash out sufficient carbon dioxide to lower the carbon dioxide tension in the blood and thus produce hypocapnea If the reduction in carbon dioxide tension is suf

CHAPTER II

TERMINOLOGY

THERE exists much confusion in the terminology used in Respiration and Oxygen want for the continued use of some of the older terms results in ambiguity Some of the perplexity is the result of changing concepts of disturbances in physiology There is thus need for revision and definition of much of the language employed

Tidal volume is the quantity of air drawn into and expelled from the lungs with each respiration *Minute volume exchange*, or *minute volume respiration*, is the amount of air which passes in and out of the lungs in the course of a minute It is calculated by multiplying the tidal air by the respiratory rate per minute

Anatomical dead space is the volume of the respiratory passages extending from the nostrils to and including the terminal bronchioles This space varies very little in capacity A moderate increase or decrease may occur as a result of bronchiolar dilation or constriction *Physiological, Virtual* or *Effective dead space* are terms applied to the total space within the lungs which just prior to expiration contains perfectly fresh air that is air which has not diluted the alveolar air or come into contact with the respiratory epithelium This volume varies with the depth of respiration In depressed states the tidal exchange may not be sufficiently great to allow fresh air to be drawn in as far as the terminal bronchioles The physiological dead space is then less than the anatomical Carbon dioxide elimination and oxygen uptake under such circumstances is dependent upon diffusion Because of pressure gradients carbon dioxide will tend to diffuse out of the alveoli towards the trachea and oxygen will travel in the reverse direction Diffusion alone will produce neither satisfactory elimination of carbon dioxide nor absorption of oxygen The physiological dead space is larger than the anatomical during increased amplitude of respira

cumstances as oxygen want develops carbon dioxide accumulates In the other form however, there is no interference with breathing except as a terminal event This type of asphyxia they explained could be produced by the inhalation of nitrogen or by deprivation of oxygen Since here there may be no interference with carbon dioxide elimination oxygen want alone exerts a direct action on the body Hence the second type of asphyxia which Henderson and Haggard described is not truly asphyxia, but is anoxia and acarbia

'*Anoxia* is defined as a failure of tissue to either receive or utilize an adequate amount of oxygen The term *oxygen want* has been used interchangeably with anoxia The term anoxia literally means without oxygen This condition is not compatible with life so Wiggers (393) first used the term '*hypoxia* in 1940, to designate milder degrees of oxygen deprivation He suggested that the term hypoxia be used when the oxygen in the inspired air is above 12 per cent and that the term anoxia be employed when the inspired air contains percentages of oxygen below 12 per cent This arbitrary distinction I believe is not satisfactory because regardless of the amount of oxygen in the inhaled atmosphere severe oxygen want may be present in tissue Indeed it is possible that tissue may be severely deprived of oxygen even when the patient is breathing it in concentrations of 60 to 100 per cent

Waters (386) also attempted to make a distinction between hypoxia and anoxia He feels that the term hypoxia should be used for any reduction in the tension of oxygen which produces disturbances of function *only* while the reduction exists Hypoxia therefore he holds has completely reversible effects He states that the term anoxia should mean a reduction in tension of such a degree that it is followed by changes of function persisting *after* the lowered tension is relieved But by his own statement Waters agrees that an immediate decision cannot always be made as to which word ought to be used on any particular occasion

The distinction therefore between anoxia and hypoxia on the basis of either the percentage of oxygen in the inhaled atmosphere or on the effects produced by oxygen want is not clear and as a

ficiently great the stimulus to respiration is lost and acapnea results

The lowering of carbon dioxide in the blood by hyperpnea is associated with a proportional decrease in the alkaline bicarbonate This condition is termed *acarbia*

C CHANGES IN THE BLOOD

Haldane in 1919 (193) and Barcroft in 1920 (42) spoke of '*anoxemia*' Strictly defined anoxemia means without oxygen in the blood This then is a state not compatible with life The term has been variously used to denote both low oxygen in the blood and oxygen want of tissue A more descriptive term, '*hypoxemia*,' signifying a decrease in the amount of oxygen in the blood should be used preferably

It is possible by the inhalation of 100 per cent oxygen by the normal individual to increase the oxygen content of arterial blood so that 100 cubic centimeters of arterial blood would carry more than 22 instead of the normal 19–20 cubic centimeters of oxygen This relative increased saturation may actually be a *hyperoxemic* state

D CHANGES IN OXYGEN TENSION IN TISSUE

Asphyxia —By derivation, this term means without pulse By common usage asphyxia has become synonymous with the frequently used term anoxia This use of the term asphyxia is unfortunate for it is important that one distinguish between the effects of oxygen deprivation alone and those of oxygen paucity in the presence of retained carbon dioxide Under experimental conditions the effects of one may be tremendously different from those of the other The term asphyxia should be limited to that state of oxygen want which is associated with a condition of increased carbon dioxide tension in the blood and tissues

Henderson and Haggard (209) recognized two forms of asphyxia One is caused by cessation of breathing There is then an excess of carbon dioxide in the body This can be caused by anything which stops respiration such as mechanical obstruction of the trachea or drugs which paralyze respiration Under such cir

Total lung capacity—the amount of air present in the lungs after a forced inspiration

Inspiratory capacity—the volume breathed by a forced inspiration following a normal expiration

Vital capacity—the maximum amount of air breathed after a forced expiration

Functional residual capacity—the amount of air in the lungs at the termination of a normal expiration

Residual volume—the volume of air present in the lungs after a forced expiration

Expiratory and *inspiratory reserve volumes*—the volumes which can be inhaled or exhaled at the termination of inspiration or expiration respectively

These authors also proposed a set of uniform symbols for use in training and in research publications relating to respiratory physiology

result is not satisfactory The term 'hypoxia' should be used to designate states of decreased availability to, or diminished utilization of oxygen by tissue from any cause or to any degree

E LUNG VOLUMES

There has been great need for the establishment of a set of definitions for lung volumes Many of the current terminologies employed for this purpose are in conflict Similar terms often mean different things To correct this a group of physiologists met in 1950 and submitted a table of definitions (365) which, it is hoped

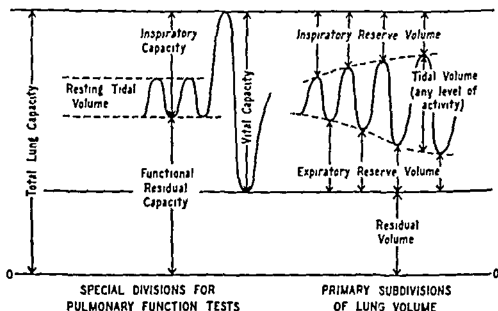


Figure 1 Lung volumes (From Standardization of Definitions and Symbols in Respiratory Physiology *Federation Proceedings* 9 3 September 1950)

will have universal applicability Figure 1 is from the article published by them and shows diagrammatically the proposed definitions of lung volume They state The primary subdivisions of the lung volume shown at right apply to all levels of respiratory effort and contain no overlapping volumes The capacity terms at left include two or more of the primary subdivisions and are specially convenient for clinical applications where gasometric measures are most simply made from the expiratory position of the resting patient

tion follows only after a pause In some disease states the Hering Breuer reflex becomes sensitized, for when the lungs are engorged or in some way rendered less elastic breathing is commonly rapid and shallow Under such conditions the receptors discharge much more readily for any given degree of distention or collapse of the lungs with the result that the tidal exchange is reduced and the respiratory rate is increased

Section of the vagi abolishing the Hering Breuer reflex is followed by deeper and slower respiration, the result of loss of inhibitory impulses from the lungs

Periodicity Since respiration continues rhythmic after section of the vagi there must be some other control over rhythmic breathing Pitts (298) states there are two divergent views as to the nature of this mechanism One of these views maintains that the periodicity of breathing is impressed upon the neurons of the respiratory center by an inhibitory mechanism which lies within the brain stem and which functions in a manner analogous to the vagal inhibitory mechanism The second view holds that the periodicity of breathing depends upon properties inherent in the neurons of the respiratory center

The brain stem inhibitory mechanism was named the pneumotaxic center by Lumsden (262) Its exact limits have not been accurately defined but it lies within the tegmentum rostral to the medullary respiratory center It is connected with the inspiratory and expiratory divisions of the respiratory center by pathways which lie in the lateral part of the brain stem These pathways carry impulses from the inspiratory center to the pneumotaxic center and from the pneumotaxic center to the expiratory center The functioning of this mechanism is said to account for rhythmicity of the breathing after the vagi are severed Since it is important that we consider both views it is necessary that we review the evidence upon which these beliefs are based Respiration following transection of the brain at the junction of the pons and the medulla remains essentially normal until such time as the vagi are severed When one vagus nerve is cut inspiration is prolonged and breathing slows When both are sectioned the animal inspires deeply and remains in a state of inspiratory spasm known as apneusis Lumsden believes apneusis is the result of continuous dis

CHAPTER III

PHYSIOLOGICAL CONSIDERATIONS

A REGULATION OF RESPIRATION

1 NEURAL CONTROL

The rate and volume of pulmonary exchange to serve the needs of the moment are the results of highly integrated nervous muscular and chemical mechanisms The coordinating mechanism the respiratory center lies within the medulla oblongata and the greatest concentration of potentials synchronous with respiration is in the region of the obex Pitts Magoun and Ranson (299) demonstrated within this center two types of responses to stimulation—inspiratory and expiratory The ventral portion of the respiratory center is concerned with inspiration and the dorsal expiration Repeated stimulation of either of these areas alone leads to a continued state of inspiration or expiration depending upon the site of stimulation for the synaptic connections linking the two centers are reciprocally inhibitory Stimulation of one center leads to inhibition of the other Stimulation of both centers simultaneously produces inspiration showing that the inspiratory center is the dominant one

Hering Breuer Reflex Afferent impulses along the vagi from receptors within the lungs affect respiratory rhythm and amplitude The receptors within the lungs are stimulated mechanically by stretching and collapse They are not sensitive to changes in chemical composition of the air within the lungs Hering and Breuer in 1868 (215) demonstrated that overinflation of the lungs inhibits inspiration and produces expiration Sharp overdeflation initiates inspiration During normal respiration pulmonary expansion terminates inspiration and excites expiration Deflation of the lungs during normal expiration does not of itself produce inspiration for expiration is normally passive and the succeeding inspira

Rosenthal (315) suggested that pulmonary ventilation is controlled by the level of oxygen in the arterial blood in 1880 In 1905 Haldane and Priestley (191) advanced the theory that respiration is controlled by the arterial carbon dioxide tension In 1911 Winterstein (100) suggested that ventilation is controlled by the arterial pH It is now known that no single chemical agent is the sole controlling mechanism Gray (183) states that The simplest hypothesis is that the individual or partial effects of the separative stimuli are additive

The most important of the factors which affect respiration are the partial pressure of carbon dioxide and the hydrogen ion concentration of the arterial blood perfusing through the medulla Normally the partial pressure of carbon dioxide in arterial blood is 40 millimeters of mercury and the pH is 7 4 An increase in the pressure of carbon dioxide of 2 5 millimeters of mercury in alveolar air or in arterial blood will double ventilation whereas a similar decrease will produce apnea The inhalation of carbon dioxide can increase the maximum ventilation to about 70 liters per minute The pO (partial pressure of oxygen) and pCO_2 (partial pressure of carbon dioxide) are increased in the arterial blood with an associated drop in the pH Metabolic acidosis increases the maximum ventilation to about 35 liters per minute The arterial blood will under these conditions show an increase in pO_2 with a decrease in pCO_2 and in the pH This increase in minute volume is in contrast with a maximum ventilation of 12 liters per minute as the result of oxygen want with a resultant decrease in the pO_2 and an increase in the pH in arterial blood This providing of course that the exhaled CO is not rebreathed

The manner in which carbon dioxide serves as a stimulus to the respiratory center has long been a debated subject It was at one time believed that the activity of the center was regulated by the hydrogen ion concentration of the arterial blood carbon dioxide serving as a stimulus simply because it acted in solution as an acid (H_2CO_3) Several facts however could not be reconciled with this idea Carbon dioxide produced a much greater effect on respiration than did any other acid for a given pH change Further sodium carbonate and sodium bicarbonate when injected into the blood stream in amounts which caused equal changes in blood pH

charge by the inspiratory center and the result in turn of removal of all inhibitory influences upon inspiration Because of this it is believed by some that the rhythm of breathing depends upon the inhibitory influence exerted by the vagal and pneumotaxic mechanisms and that there is no inhibitory property within the neurons of the respiratory center itself Pitts believes that under most conditions the vagal inhibitory mechanism plays a more prominent role than the pneumotaxic mechanism in determining the rhythm of respiration

The second view that the rhythmicity of breathing depends upon properties inherent in the neurons of the respiratory center has recently received strong support by the work of Hoff and his co workers (222 75 76) Hoff *et al* have demonstrated that apneusis is not permanent neither in the dog nor in the cat for, after a variable interval the period of inspiratory spasm is terminated by an expiration This period of apneusis is also not total for they were able to demonstrate that there remain some vestiges of periodic respiration superimposed as it were on the phases of apneustic breathing Further the period of apneusis disappears in the deteriorating preparation and normal respiration reappears with the last respiratory acts of the animal essentially normal Because of these factors Hoff *et al* contend apneusis represents some process superimposed upon a basic periodic medullary rhythm They are convinced that apneustic breathing is the result of interplay of peripheral and central factors peripherally the stimulation of the carotid body mechanism by oxygen deprivation and centrally overfacilitation of inspiration which occurs when the lower part of the pons is included with the medulla in the intact portion of the brain stem These experiments suggest that the medullary respiratory center is inherently periodic and that respiration may be modified by other neural mechanisms

2 DIRECT CHEMICAL CONTROL OF RESPIRATION

The activity of the respiratory center is subject to many factors Chemical changes within the respiratory center as a result of alteration in oxygen and carbon dioxide tension the hydrogen ion concentration the rate of blood flow and the temperature of the blood alter respiration

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had opposite effects upon respiration, the former diminishing and the latter increasing pulmonary ventilation. Jacobs (227) in an endeavor to explain these apparent discrepancies showed that owing to the more ready penetration of carbon dioxide into the cells, the intracellular hydrogen ion concentration might be considerably higher than that of the surrounding medium. Gesell (172) dispelled much of the confusion concerning the theory of hydrogen ion being the essential respiratory stimulus. He postulated that the determining factor was the hydrogen ion concentration within the cells of the center itself.

Since the neurons of the respiratory center produce carbon dioxide as a result of their own activity, a reduction in the blood flow through the medulla is followed by an increase in acidity and carbon dioxide pressure within the center and, as a consequence, respiration is stimulated. On the other hand, an increase in blood flow is followed by a reduction in acidity and carbon dioxide pressure with a resultant depression of respiration. These changes in blood flow, however, are not important as they affect ventilation.

With increase in temperature the respiratory rate also increases as does the amplitude of respiration. This hyperpnea is not fully explained by the increased production of carbon dioxide during fever. There is some belief that the frequency of discharge of impulses by the respiratory neurons increases as the temperature rises with resultant increased amplitude of respiration.

The neurons in the respiratory center are depressed by a reduction in the partial pressure of oxygen in the arterial blood. With only moderate reduction in the partial pressure of oxygen a transient phase of stimulation may follow the initial depression. Such changes can be demonstrated only after the stimuli from the carotid and aortic chemoreceptors have been removed by denervation. Inhalation of high oxygen concentrations usually results in early respiratory stimulation. This is said to be the result of a pathologic increase in the oxidative process of the neurons.

3. REFLEX CHEMICAL CONTROL OF RESPIRATION

As noted previously, there is a peripheral chemical control of respiration by means of chemoreceptors located at the bifurcation

of the carotid arteries and at the arch of the aorta, known respectively as carotid and aortic bodies The carotid and aortic areas each contain two types of receptors one type (pressoreceptors) responds to mechanical the other (chemoreceptors) to chemical stimulation The pressoreceptors situated in the wall of the carotid sinus and in the wall of the aortic arch, are stimulated by a stretching force, as by a rise in arterial blood pressure The chemoreceptors are contained in small glandular structures—the carotid and aortic bodies The respiratory reflexes initiated from these two types of receptors are contrary in their effects Stimulation of the pressoreceptors inhibits respiration—an abrupt rise in blood pressure such as follows the injection of epinephrine causing respiratory arrest (epinephrine apnea) Excitation of the chemoreceptors increases the rate and depth of breathing Both types of reflex are abolished by section of the supplying nerves

Though of the utmost importance in the control of the circulation the pressoreceptors do not appear in mammals at least, to serve any respiratory function under physiologic conditions There is no condition of a physiologic nature under which the inhibition of respiration is caused by a rise in blood pressure or by the stimulation of these receptors

The chemoreceptors are stimulated by oxygen lack, but not until the oxygen tension of the arterial blood reaches a relatively low level probably 70 millimeters of mercury or less At this tension the arterial blood is about 92 per cent saturated with oxygen Breathing an atmosphere containing 18 per cent oxygen or ascent to an altitude of 4000 feet produces similar tension and percentage saturation The chemoreceptors are still less sensitive to carbon dioxide Comroe and Schmidt (101) have shown experimentally that the chemoreceptors are relatively insensitive to a rise in carbon dioxide tension and therefore play a very minor role if any in the control of respiration under ordinary physiologic conditions In more exacting emergencies however the reflex response of the chemoreceptors especially to hypoxia is of the highest importance Hypoxia appears to be ineffective as a direct stimulus to the respiratory center Depression and ultimate failure of the central neurons is the predominant effect of oxygen want The chemoreflex mechanism on the other hand according to Comroe

and Schmidt (101) is highly resistant to hypoxia retaining its viability and continuing to exert its influence upon the center which would otherwise be unresponsive in the body s emergency These observers look upon the chemoreceptor mechanism as a more primitive type of respiratory control which serves as a last line of defense against respiratory failure

In states of severe oxygen depletion the medullary center may become so depressed as to respond only to chemoreceptor stimulation The administration of oxygen may relieve the hypoxemia but it at the same time, eliminates the mechanism responsible for the maintenance of respiration Apnea may then occur (carotid body apnea) This apnea may terminate fatally if the medullary centers have been sufficiently depressed

Voluntary control of respiration is exerted during the acts of speaking swallowing laughing etc The glossopharyngeal nerve contains afferent fibers which inhibit respiration during the second stage of the act of swallowing The voluntary control over respiration however is strictly limited The breath can be held for only a brief space before automatic control asserts itself the inhibitory influence is overridden and the muscles of respiration contract despite all one s efforts to hold his breath

Stimulation of almost any afferent nerve may bring about a reflex change in respiration Stimulation of pain fibers is especially potent in this regard and the respiratory effects of the excitation of the cutaneous nerves by extremes of heat and cold are well known Stimulation of the abdominal viscera either during surgery or as a result of disease may cause profound changes in breathing Abrupt inhibition of respiration may be caused by the inhalation of an irritant gas through stimulation of nasal branches of the fifth cranial nerve

B INTRATHORACIC PRESSURES

1 INTRAPULMONARY PRESSURE

The ventilatory aspect of respiration is the movement of air into and out of the lungs This movement is the result of alterations of pressure within the thorax Two sets of pressures manifest themselves one within the pulmonary tree and the other in

the pleural space The former is known as the intrapulmonary pressure and the latter, the intrapleural pressure When the lungs are in the resting position the intrapulmonary pressure is atmospheric It drops 2 to 3 millimeters of mercury during inspiration and rises 4 to 5 millimeters of mercury during expiration The maximal negative pressure capable of being developed within the lungs by a forced inspiration against resistance is from −40 to −50 millimeters of mercury The intrapulmonary pressure might be increased to 40 millimeters of mercury by expiration against an obstruction such as a closed glottis

2 INTRAPLEURAL PRESSURE

The intrapleural pressure is normally subatmospheric from the time the chest cavity is first expanded at birth During normal inspiration the intrapleural pressure is −6 millimeters of mercury and during normal expiration it is −2 millimeters of mercury Here too these pressures may be greatly altered by respiratory efforts against an obstruction During a strong inspiratory effort with a closed glottis the intrapleural pressure may drop to −40 millimeters of mercury Forced expiration against an obstruction may develop an intrapleural positive pressure of 40 to 50 millimeters of mercury

An important result of the intrapleural negative pressure is its effect on the thin walled veins and auricles within the thorax This increase in the intrapleural negative pressure (subatmospheric) helps to fill these structures from extrathoracic regions During states of increased intrapleural pressure (greater than atmospheric) the pressure is transferred to the soft walled structures within the mediastinum and blood is forced out from these structures into the large vessels of the neck and abdomen

C OXYGEN TRANSPORT

Oxygen leaves the alveolar air and enters the venous blood because of the difference in pressure gradient present Since the venous blood oxygen is at a lower tension than the oxygen in alveolar air the venous blood thus becomes arterialized There is some disagreement as to the difference between the partial pressure of oxygen in alveolar air and that in arterial blood because

of the barrier to the passage of oxygen produced by the lining of the alveolar spaces and the walls of the lung capillaries The difference is said to be from about 1 to 9 millimeters of mercury (112)

Oxygen entering the blood may be carried both in chemical combination with hemoglobin and in physical solution The amount carried with hemoglobin and in solution depends upon the amount of available hemoglobin and the partial pressure of oxygen in the arterial blood The higher these values are the greater will be the amount of oxygen carried

Oxygen carried by hemoglobin is in the form of oxyhemoglobin One gram of hemoglobin combines with 1 34 cubic centimeters of oxygen The normal amount of hemoglobin in 100 cubic centimeters of blood is 15 grams Thus when fully saturated the hemoglobin in 100 cubic centimeters of blood carries 20 1 cubic centimeters of oxygen

The oxygen in physical solution is directly proportional to the pO_2 of the gas which is in equilibrium with the blood At normal atmospheric pressure breathing air and at 38°C 100 cubic centimeters of blood carries in physical solution, 0 3 cubic centimeter During breathing of oxygen at higher tensions the amount of oxygen physically dissolved is increased With breathing of 100 per cent oxygen 100 cubic centimeters of blood can carry approximately 2 3 cubic centimeters of oxygen in solution

D PERCENTAGE SATURATION

The extent to which hemoglobin combines with oxygen depends upon the partial pressure of oxygen of the inhaled atmosphere If normal most of the hemoglobin is combined with oxygen and is said to be 95 per cent saturated When the partial pressure of oxygen in the inhaled atmosphere is low less hemoglobin is combined with oxygen The extent of the combination of hemoglobin with oxygen is discussed in terms of the percentage saturation of the hemoglobin The relationship between the percentage saturation and the pressure of oxygen is expressed in the oxygen dissociation curve of hemoglobin The character and the shape of the dissociation curve depends also upon the partial pressure of carbon dioxide (pCO) in the blood and upon its

temperature The dissociation curve of hemoglobin and the partial pressure of carbon dioxide is, under normal conditions plotted as the middle line (40 mm pCO_2) in Figure 2 A change to the acid side (90 mm pCO_2) that is an increase in the pCO_2 will shift the oxygen dissociation curve to the right A decrease

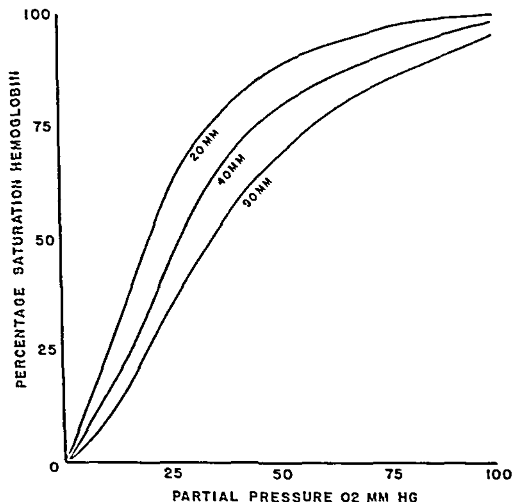


Figure 2 Oxygen dissociation curve showing the effect of a drop in carbon dioxide tension toward alkalosis (20 mm) and toward acidosis (90 mm)

in the pCO_2 or a rise in the pH will shift it to the left (20 mm pCO_2) A shift in the oxygen dissociation curve to the right increases the amount of oxygen given up to the tissues The influence of carbon dioxide in this regard was discovered by Bohr and is referred to as the Bohr effect

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CHAPTER IV

CLASSIFICATION OF HYPOXIA

Barcroft (12) classified anoxia into three types Anoxic, Anemic and Stagnant Peters and Van Slyke (296) added a fourth form Histotoxic A better working classification is that of Saklad *et al* (324) Similar in some respects to that of Barcroft Peters and Van Slyke it subdivides the Anoxic Anoxia of the latter classification substitutes Hemoglobic Hypoxia for Anemic Anoxia and adds Demand Hypoxia Hypoxia is divided into seven groups based upon the etiological circumstances of each

A Atmospheric Hypoxia
B Tidal Hypoxia
C Alveolar Hypoxia
D Hemoglobic Hypoxia
E Stagnant Hypoxia
F Histotoxic Hypoxia
G Demand Hypoxia

A ATMOSPHERIC HYPOXIA

Atmospheric Hypoxia is due to a reduction in the availability of oxygen to tissue because of a diminution in the partial pressure *of oxygen in the inhaled atmosphere Such a diminution in the* pO_2 may be the result of

1 High altitudes
2 Vitiation of atmosphere by dilution with inert gases (anesthetic)
3 Unventilated places

B TIDAL HYPOXIA

Tidal Hypoxia is the result of a decrease in oxygen uptake by tissue because of a decreased respiratory exchange This form of oxygen want may be the result of disease drugs respiratory obstruction or because of altered respiratory dynamics

E CARBON DIOXIDE TRANSPORT

Hemoglobin plays a role also in the transport of carbon dioxide About 5 per cent of the carbon dioxide in the blood is dissolved as such in the plasma Two to 10 per cent depending upon the degree of oxygenation of the hemoglobin is combined directly with hemoglobin (carbhemoglobin) The remainder is present as bicarbonate and as such is combined with base which has been yielded to carbonic acid by the weak acids of the blood

The carbon dioxide combining power of reduced blood is greater than that of oxygenated blood because reduced hemo globin is a weaker acid than oxyhemoglobin and the reduced hemoglobin can combine directly with more carbon dioxide to form carbhemoglobin than can oxygenated hemoglobin

Base yielded by hemoglobin participates indirectly in the car riage of carbon dioxide by the plasma by means of the chloride shift Base within the cells neutralizes the chloride ions which enter the red cells thereby leaving base in the plasma free to neutralize HCO_3 ions

In some forms of Atmospheric Hypoxia (high altitudes unventilated spaces) the arterial CO_2 pressure may be lowered because of a washing out of CO_2 by hyperventilation An important factor in the dissociation of oxygen from hemoglobin is the carbon dioxide tension of arterial blood In these circumstances, the oxyhemoglobin does not give up its oxygen readily and as a consequence the tissues suffer further

D HEMOGLOBIC HYPOXIA

In this condition the total load of oxygen is reduced in proportion to the reduction in hemoglobin content as in hemorrhage, or to a reduction in the amount of available hemoglobin as in carbon monoxide poisoning Arterial oxygen tension and the amount of oxygen in simple solution is normal and the hemoglobin present in arterial blood is 95 per cent saturated

Hemoglobic Hypoxia may be produced by

1 Blood loss acute or chronic
2 Red cell destruction by poison or disease
3 Reduction in the amount of available hemoglobin by carbon monoxide poisoning
4 Alteration in hemoglobin by nitrites or chlorates
5 Decreased production of red blood cells

E STAGNANT HYPOXIA

This condition is the result of a slowed circulation The arterial oxygen saturation oxygen load and its oxygen tension, are all normal The arteriovenous difference of oxygen however, is increased because more oxygen is taken up by the tissues as a result of the slowed circulation Venous blood is therefore characterized by a low percentage saturation of oxygen

Stagnant Hypoxia may be produced by

1 Circulatory failure
   a General
   b Local—Raynaud s disease
2 Impaired venous return
3 Shock
4 Military aviation—heart cannot pump blood against high centrifugal forces developed during rapid turns dives pull outs etc

Disease

1 Cerebral lesions—tumor abscess, edema
2 Meningitis
3 Medullary paralysis poliomyelitis
4 Asphyxia neonatorum—traumatic extraction

Drugs

1 Morphine
2 Barbiturates
3 Anesthetics

Respiratory obstruction

1 Pharyngeal
2 Laryngeal
3 Tracheal
4 Bronchial

Altered Respiratory dynamics

1 Convulsions
2 Emphysema
3 Shifting mediastinum
4 Paradoxical respiration
5 Intercostal paralysis (partial or complete)

Reflex inhibition of respiration

C ALVEOLAR HYPOXIA

Alveolar Hypoxia is a state of oxygen want due to decrease in the number or efficiency of functioning alveoli This may be the result of involvement of the alveoli by pneumonia or emphysema compression of the alveoli by atelectasis or pleural effusion or a decreased alveolar efficiency as may be caused by intrapulmonary exudate

In the Atmospheric Tidal and Alveolar forms of hypoxia the oxygen saturation of arterial blood is below its normal of 95 per cent The oxygen content of the arterial blood falls below the usual 19 5 volumes per cent Coincident with the lowered per centage saturation and oxygen content the oxygen partial pres sure in arterial blood is lowered

Hypothetical values of arterial and venous oxygen percentage saturation and volumes per cent are shown in the various forms of oxygen want in Table 1 Table 2 summarizes the oxygen capacity arterial oxygen content and tension, venous oxygen content and tension and arteriovenous difference in the various forms of hypoxia

TABLE 1

Blood values in various forms of hypoxia

Classification Hypoxia	*Arterial Oxygen*		*Venous Oxygen*	
	% Sat	*Vol %*	*% Sat*	*Vol %*
Atmospheric, Tidal, Alveolar	75	15	50	10
Hemoglobic	95	10	35	5
Stagnant	95	19 5	30	5
Histotoxic	95	19 5	85	17
Demand	95	19 5	50	10
Normal	95	19 5	70	14

TABLE 2

Oxygen capacity, content tension and arteriovenous difference in various forms of hypoxia

Hypoxia	*Oxygen Capacity*	*Arterial Oxygen*		*Venous Oxygen*		*A V Difference*
		Content	*Tension*	*Content*	*Tension*	
Atmospheric	Normal	Decreased	Decreased	Decreased	Decreased	Decreased
Tidal	Normal	Decreased	Decreased	Decreased	Decreased	Decreased
Alveolar	Normal	Decreased	Decreased	Decreased	Decreased	Decreased
Hemoglobic						
Carbon Monoxide	Decreased	Decreased	Normal	Decreased	Decreased	Decreased
Hemorrhage	Decreased	Decreased	Normal	Decreased	Decreased	Decreased
Stagnant	Normal	Normal	Normal	Decreased	Decreased	Increased
Histotoxic	Normal	Normal	Normal	Increased	Increased	Decreased
Demand	Normal	Normal	Normal	Decreased	Decreased	Increased

In clinical medicine hypoxia is usually of mixed types The state of hypoxia may have been originally due to a single type The disease as it progresses produces other forms of hypoxia For example a patient acutely ill with pneumonia originally may have

F HISTOTOXIC HYPOXIA

Peters and Van Slyke (296) first discussed this form of oxygen deficiency in 1931 It is a form of hypoxia in which the utilization of oxygen by the cells is interfered with It is the only form of hypoxia in which venous oxygen saturation is higher than normal Arterial oxygen saturation oxygen content and oxygen tension are normal The blood in passing through the tissues does not unload its oxygen consequently the arteriovenous difference is extremely small

Histotoxic Hypoxia may be produced by

1 Alcohol
2 Anesthetics
3 Cyanide
4 Carbon monoxide
5 In general any agent which depresses cellular respiration

Keilin (230) showed that alcohol stabilized the oxycytochrome so that the oxygen could not be removed at a normal rate from the blood stream He showed further that cyanide produced Histotoxic Hypoxia by inactivating the iron containing oxygen carrier of the tissue cell Cyanide inactivates cytochrome by preventing its combination with oxygen

G DEMAND HYPOXIA

Under this heading are included those metabolic conditions in which the bodily requirements for oxygen are elevated above normal

1 Hyperthyroidism
2 Hyperpyrexia—disease or artificially produced
3 Blood dyscrasias

The oxygen want may early in these conditions be but potential The added oxygen requirements are met early by an improved circulatory and respiratory efficiency As the oxygen need increases this compensatory effort may not be adequate The added oxygen uptake from the arterial blood continues The arteriovenous difference increases If oxygen uptake by the red blood cells is not facilitated by an increase in the percentage of oxygen in the inhaled atmosphere true hypoxia becomes evident

CHAPTER V

PATHOLOGIC CONSIDERATIONS

It was early discovered that there is great variation in susceptibility to oxygen want Of the three individuals that ascended in the balloon, Zenith to 28 200 feet in 1875 one survived and two died It should be obvious, then, that the one who survived was better able to tolerate the effects of oxygen want In more recent times, it has been pointed out that at elevations of 7,000 to 14 000 feet some individuals may have symptoms of oxygen deprivation and others may have no untoward effects Barcroft and his co workers (13 14) in 1931 described excessive sensitivity to oxygen want in a 26 year old man A great variation in susceptibility of dogs to oxygen want was shown by Davis (115) The ability of dogs to withstand oxygen want better than cats was explained by Stacy and Whitehorn (363) as due to the greater ability of dogs to increase their ventilatory volume because of greater response to chemoreceptor stimulation Robert Boyle and Paul Bert noted that resistance to oxygen deprivation is greater in very young animals than in adults

A THE RESPIRATORY SYSTEM

The response of the body to hypoxia is an effort to compensate for oxygen lack There is an effort to take up more oxygen by respiration and to deliver it more rapidly to tissues by the circulation

The respiratory center itself can respond satisfactorily to carbon dioxide only if it is well supplied with oxygen If the extent of hypoxia is not great and there is some associated carbon dioxide retention the center is stimulated If the respiratory threshold is greatly elevated by hypoxia response to carbon dioxide stimulation is absent The chemoreceptors in the aortic and carotid bodies then become activated and this in turn causes the respira

been suffering from Alveolar Hypoxia because of a decrease in alveolar surface His respiratory exchange soon becomes diminished and Tidal Hypoxia plays an important role The temperature rise with an associated increased metabolism demands that more oxygen be furnished Because of Alveolar and Tidal Hypoxia such increased oxygen need is not met, and we now have an added Demand Hypoxia With aggravation of the disease the circulatory system may soon become inadequate and a degree of Stagnant Hypoxia may supervene

oxygen want is followed by a loss of carbon dioxide and a resultant lowering of the carbon dioxide tension in the arterial blood He attributed this loss to the lowered barometric pressure directly We now know that carbon dioxide loss is the consequence of hyperventilation which is the result of this form of oxygen want To maintain a normal acid base balance more base is excreted by the kidneys The excretion of bicarbonate by the kidneys con

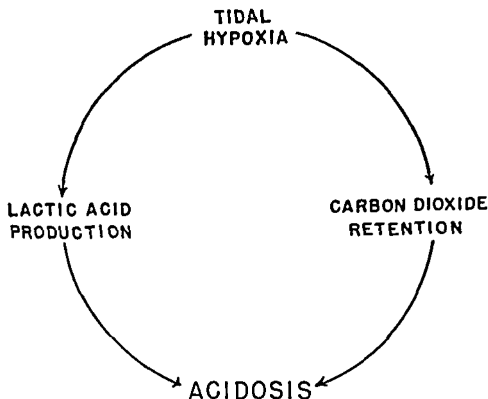


Figure 4 Acidosis as a result of Tidal Hypoxia

tinues until the plasma bicarbonate is lowered in the same proportion as is the carbon dioxide tension with the production of acapnia and acarbia If carbon dioxide loss continues and compensation cannot be maintained alkalosis supervenes (Figure 3)

In disease however there are always accompanying factors which alter the picture The respiratory pattern is different Atmospheric Hypoxia of inhalation anesthesia Tidal Hypoxia of spinal anesthesia or respiratory obstruction Alveolar Hypoxia of pneumonia or pulmonary edema are not always pure types A common characteristic is carbon dioxide retention Carbon diox

tory center itself to become more active Whatever the driving force there is at first an increase in the minute volume of breathing The increase in pulmonary ventilation not only increases the oxygen uptake by blood but aids in the elimination of carbon dioxide If oxygen lack is progressive, respirations become irregular rapid and shallow Factors in addition to oxygen lack which may further elevate the respiratory threshold and thus decrease

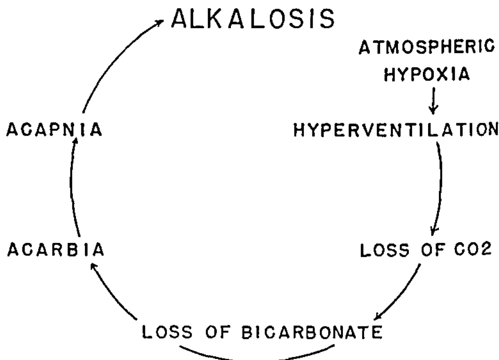


Figure 3 Alkalosis as a result of Atmospheric Hypoxia

the ability of respiration to compensate by increased minute volume exchange are respiratory depressants such as morphine barbiturates and anesthetic agents

Most of our knowledge of the pathologic physiology of oxygen want was discovered at high altitudes and in low pressure atmospheres produced by chambers The type of oxygen want that served as a basis for these studies was of a pure type that due to a decrease in total barometric pressure or to a decrease in the partial pressure of oxygen without other factors which might have complicated the response From studies of oxygen want due to a decrease in total barometric pressure Mosso showed that

early in oxygen want acts to increase the perfusion of tissues and normally compensates for the hypoxemia As hypoxemia continues the flow in the inferior vena cava begins to fall and is markedly reduced even though the blood pressure in the superior vena cava may still be above control values, with an apparent redistribution of blood to the vital head regions Continuance of the hypoxemia results in a fall in the superior vena cava flow as well as in the inferior vena cava flow This is furthered by progressive cardiac failure

Van Loo *et al* (382) termed the early blood pressure rise as the hypoxemic pressor phase, which is followed by the hypoxemic depressor phase However, when air is substituted for nitrogen in experimental hypoxic animals there is a second pressor effect known as the post hypoxemic rise which is frequently greater in magnitude than the primary pressor effect This suggests that during the depressor phase substances are elaborated which could not exert their pressor effect or be quickly destroyed in the presence of oxygen With re-oxygenation the pressor action of these substances becomes manifest They found that injected epinephrine acts similarly with no pressor effect during the late hypoxemic depressor phase, but as soon as air breathing is resumed a pressor effect is evidenced They feel that the pressor material liberated during the hypoxemic phase is epinephrine like in action They conclude that the adrenal gland plays little part in the production of the hypoxemic pressor response, but plays a major role in the production of the arterial pressor response after reaeration Pressor material liberated from the adrenal during severe hypoxemia does not exert pressor effect until tissues are re oxygenated

1 THE EFFECT OF OXYGEN WANT ON THE CORONARY CIRCULATION

It has been shown that oxygen want is a powerful vasodilator of the coronary vessels (220) with a resultant improved flow of blood to cardiac musculature This may occur without any relationship to changes in systolic pressure and is undoubtedly a very valuable compensatory mechanism In this connection it is *important* to note that Wiggers (393) has stated The pronounced

ide has been shown to have, of itself a powerful effect on body processes Carbon dioxide can alter heart rate, cardiac output, blood volume flow blood pressure capillary pressure and possibly lymph flow Carbon dioxide alters acid base balance of the blood the oxygen dissociation curve, etc The diminished elimination of carbon dioxide due to inefficient respiration and the increased production of lactic acid due to hypoxia tend to produce an acidosis (Figure 4)

In summary the respiratory center normally sensitive to carbon dioxide is stimulated if hypoxia is associated with some carbon dioxide retention The respiratory threshold however, becomes elevated with increasing deprivation of oxygen The respiratory center is then less sensitive to stimulation by carbon dioxide The carotid body mechanism serves as the driving force to stimulate respiration if either the respiratory threshold becomes elevated or the arterial oxygen tension drops

In Atmospheric Hypoxia the resultant response is hyperpnea If the exhaled gases are not rebreathed the carbon dioxide loss becomes excessive and respiratory alkalosis may appear In most diseased states oxygen deprivation is associated with carbon dioxide retention with a resultant tendency to respiratory acidosis This acidosis may be further enhanced by the presence of an increased production of lactic acid

B THE CARDIOVASCULAR SYSTEM

The circulatory response to oxygen deprivation runs closely parallel to the respiratory reaction The coronary and cerebral vessels dilate pulse and blood pressure are elevated and cardiac output is increased (125 201 234 265) These aid in the delivery of oxygen to tissue and carriage of carbon dioxide to the lungs for elimination The increase in pulse rate is not maintained if the oxygen want continues to be increased It becomes reversed and slows down If the oxygen want increases and the oxygen saturation falls 35 to 50 per cent a reduction of cardiac output and a fall in blood pressure take place Atmospheric Hypoxia improves the circulation until the amount of oxygen in the inspired air falls to 9 per cent It is at this point that a crisis occurs (327)

'Feldman *et al* (150) showed that the augmented blood flow

aortic bodies In the presence of oxygen want these centers send afferent impulses to the vasomotor center and there is a reversal of the blood pressure due to a depression of vasomotor tone As previously stated much of the response to oxygen want depends upon the mechanism by which it is produced Under conditions where carbon dioxide retention is possible, some of the blood

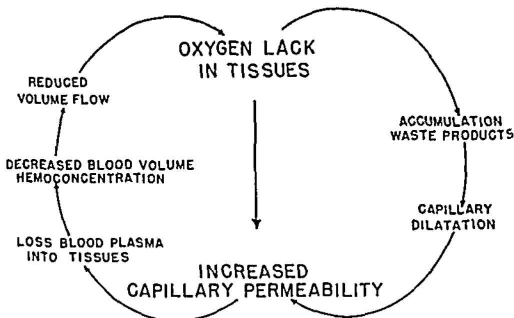


Figure 3 The vicious cycle of oxygen deprivation and increased capillary permeability

pressure rise may be due to the retained carbon dioxide Gellhorn and Lambert (169) showed that the rise in blood pressure due to carbon dioxide is brought about by action directly upon the vasomotor center and to a lesser degree on the chemoreceptors In the presence of intact carotid and aortic bodies and in the presence of retained carbon dioxide oxygen want will produce a very marked rise in blood pressure Carbon dioxide has a stimulating effect on the vasomotor center Its action on the carotid and aortic bodies is not great

4 THE EFFECT OF OXYGEN WANT ON THE CAPILLARIES

The capillaries are especially vulnerable to oxygen deprivation Such deprivation injures capillary endothelium with resultant relaxation and dilation These small vessels lose their normal

anoxic vasodilatation is doubtless a providential mechanism by which the cardiac pump is sustained so well in progressive anoxia. *Indeed it is probable that myocardial stimulation is converted* into myocardial depression as soon as the augmentation of coronary blood flow cannot keep pace with the decreasing volume of oxygen carried by the blood.

Eckenhoff and his group (137, 138) demonstrated that in the presence of hemorrhage and circulatory failure the portion of the cardiac output which is diverted into the coronary circulation increases from the normal 4 to 5 per cent to 15 per cent or more. Burdette and Wilhelmi (79) showed that the oxygen uptake by cardiac muscle is depressed in the presence of severe hemorrhagic shock. *Under conditions of oxygen want there are three mechanisms* which protect the heart: 1) A decrease in the tonicity of the coronary vessels, 2) a diversion of a larger fraction of the cardiac output into the coronary circulation and 3) a decrease in cardiac work.

2 THE EFFECT OF OXYGEN WANT ON THE CONDUCTION OF THE NORMAL CARDIAC IMPULSE

It has been shown by Resnik (308) that the S A node is highly sensitive to oxygen want and that there is a brief period in which the impulse formation is accelerated but that this period is rapidly followed by progressive slowing of the intrinsic rate of the heart. Oxygen want first produces a shortening and later a lengthening of the A V conduction. Intraventricular conduction, however, is only slightly affected. It is Resnik's feeling that these changes are the result of myocardial hypoxia.

The T wave becomes either decreased or inverted. During severe degrees of oxygen want there is a slowing of the conduction rate as evidenced by a lengthening of the P R interval.

It was found (199) in dogs that clamping a coronary artery frequently causes ventricular fibrillation while generalized oxygen want almost invariably resulted in ventricular standstill instead.

3 THE EFFECT OF OXYGEN WANT ON THE BLOOD PRESSURE

It is generally agreed that the rise in blood pressure associated with acute oxygen want is due to the action of the carotid and

oxygen provided that the exposure to hypoxia had been brief An increased flow of lymph followed an increase in pulmonary capillary pressure and a change in the capillary permeability Drinker stated that oxygen lack leads to an increased capillary permeability of the blood capillaries all over the body He pointed out that the capillaries in different parts of the body vary as to their resistance to oxygen lack and their ability to contract The endothelium of those of the lung are among the least resistant to low oxygen tensions

Filtration through endothelium is a function of the pressure within the capillary the condition of the vessel wall the osmotic action of the plasma proteins and the tissue pressure

During hypoxia fluid accumulates in the alveolar wall impeding the passage of gases through into the alveolar spaces further obstructing the passage of oxygen and carbon dioxide The thickening of the wall and the fluid in the alveolus close the pulmonary pores that are essential for the transport of oxygen between the alveoli These pores intercommunicating channels between primary lobules though relatively unimportant in normal respiration may in the presence of obstruction supply as much as 10 per cent of its normal ventilation Without these pores obstruction of a respiratory bronchiole leads to rapid absorption of the gas behind it with resultant atelectasis There is also a slight diffusion from one alveolus to another but this is also barred by the swelling of the alveolar wall The pathological process augments itself by further producing hypoxia of the alveoli concerned which lowers the total tension of oxygen throughout the capillary bed Drastich *et al* (124) showed that dogs with 50 per cent of their lung tissue removed tolerated the oxygen lack produced by exercise far better than those with part of a lung atelectatic Lung tissue that is unable to transport oxygen continues to use oxygen thus lowering the tension in the capillary bed The presence of atelectatic areas in the lungs further is responsible for a diminution in arterial oxygen saturation since much unoxygenated blood may pass through the atelectatic lung reaching the left heart without having taken up any oxygen

The transudation and exudation of fluid carries protein into alveolar spaces This proteinized fluid exerts osmotic effect which

tone and their ability to contract and their lumina become packed with stagnant red cells (241) Permeability of the walls of these vessels to fluid and plasma protein is markedly increased (243) Their normal endothelium is readily permeable to the passage of water and crystalline solutes in either direction and is readily impermeable to plasma proteins If the capillary permeability is increased because of damage by oxygen deprivation plasma proteins leave the circulation Such loss alters the osmotic pressure of blood and fluid balance is upset

Blood flow is further decreased because of accumulation of waste products the result of decreased oxygen supply which in turn aggravates the atony and dilation of capillaries (275 351) The effect of oxygen deprivation on capillary permeability results in a vicious cycle (Figure 5)

SUMMARY OF CIRCULATORY EFFECTS OF HYPOXIA

The early response to hypoxia is an increased efficiency of the cardiovascular system Coronary flow is increased as are pulse rate cardiac output and blood pressure Conduction disturbances however, may become manifest If oxygen deprivation continues the blood pressure, pulse rate and cardiac output fall If the cardiovascular system has not deteriorated relief of the hypoxia may be followed by a post hypoxemic blood pressure rise Capillary endothelium is especially sensitive to oxygen deprivation with a resultant increased permeability It is the loss of the normally intravascular protein which is responsible for disturbed fluid balance and peripheral vascular collapse

THE PULMONARY TREE

Drinker (128) discussed the effect of hypoxia on the lung capillaries in a series of lectures on pulmonary edema and inflammation He measured the flow of lymph from the lungs and found that the flow increased during dyspnea Lymph channels in the lungs that extend only as far as the alveolar ducts were adequate to keep the lung lobules and alveoli dry except in the presence of hypoxia Subnormal tensions of oxygen in the lungs caused an immediate increase in the volume of lymph produced This excess flow would cease when the animal was ventilated with pure

stricted by decreased carbon dioxide or increased oxygen The dilator effect of low (10 %) oxygen actually is practically equal to that of high (5-7 %) carbon dioxide the greater total effect of the latter being attributable to an associated rise in blood pressure that was lacking in the anoxia determination Thus man's cerebral vessels appear to possess the capacity both of the monkey's to be markedly dilated by anoxemia and of the cat's to be strongly dilated by increased carbon dioxide The effect of the inhalation of 100 per cent oxygen instead of room air was relatively weak (a decrease of about 12 per cent cerebral blood flow) It would seem that carbon dioxide tension is the dominant influence in regulating both the tone of cerebral blood vessels and the activity of the respiratory center over the ordinary physiologic range

Oxygen want because of localized vasodilation produces an increased flow of blood to the brain particularly to the medulla and the hypothalamus Associated with this is dilation of pial vessels How much of this is due to carbon dioxide retention and how much of it is due to oxygen lack is debatable The amount of damage which will be suffered by the brain depends on the degree of oxygen want If the degree of oxygen want is not great the brain may not suffer because of the increased blood volume flow and the vasodilation There soon however comes a point wherein vasodilation cannot keep pace with the increasing deficit of oxygen in the arterial blood There is no structure in the body wherein damage due to oxygen want is less likely to be reversible as is nervous tissue Whereas in other parts of the body reparative processes can alter much of the damage due to oxygen want the reparative processes in the brain are at a minimum

Courville (107) states It has been recognized that the evil effects of anoxia are most evident in the tissues of the brain and that it is the cerebral lesions which produce the most crippling and fatal residuals Gildea and Cobb (178) noted that temporary interference with the cerebral circulation produces areas of focal necrosis in the cerebral cortex

The following table from Drinker lists the survival time of different nerve tissues completely deprived of blood

Cerebrum small pyramidal cells	8 minutes
Cerebellum Purkinje cells	13 minutes

opposes that of the plasma proteins in the capillaries It eventually may fill the lung lobule so that it cannot be cleared by coughing Having filled the bronchiole it may spill into other lobules to involve them in the cycle of hypoxia and edema

With diminished tidal exchange and respiration irregular in depth the output from the right heart is low for there is less suction on the great veins There is less total blood flow through

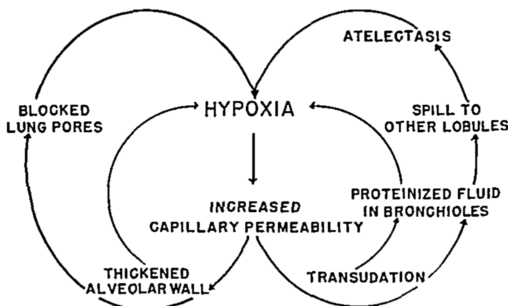


Figure 6 The vicious cycle of oxygen want and increased capillary permeability in the lungs

the lungs and capillaries in the dependent portion of the lungs are by passed There is stasis in those vessels Air does not enter these alveoli as well as under normal conditions Hypoxia and also accumulation of lymph and edema is augmented The vicious cycle thus engendered may be summarized as in Figure 6

C THE CENTRAL NERVOUS SYSTEM

1 GENERAL CONSIDERATIONS

Kety and Schmidt (231 233) studied the changes in arterial gas tensions on cerebral blood flow in normal men Schmidt (334) states According to these findings the cerebral vessels of man are dilated by increased carbon dioxide or decreased oxygen con

may appear as a result of an effect upon the optic nerves or by secondary changes in the occipital lobe resulting from acute oxygen want and vascular occlusions Ganglionic symptom complexes may appear as the result of injury to the globus pallidus Speech disturbances and peripheral neuritis may occur, the latter seems to be unique in carbon monoxide poisoning Chronic psychoneuroses occur in many of the patients who recover from carbon monoxide poisoning The symptoms may persist for months or years The most characteristic features are emotional flattening and changes in personality with poor insight, indifference, obtuseness anxiety, hazy memory, emotional depression poor judgment and deficiency in initiative Aberrations appear, some being present in almost every patient who recovers The psychosis may be permanent and even progressive to complete dementia with amnesia, confusion irrationality emotional depression and delusions of persecutory nature The incidence of serious psychosis however is low

3 CHANGES DUE TO OXYGEN WANT AS A RESULT OF ANESTHESIA

Anesthesia may produce hypoxia by 1) Depression of the respiratory center The respiratory center may be depressed by drugs such as pentothal ether cyclopropane and avertin 2) Diminution of oxygen in the inhaled atmosphere Oxygen may be diminished in the inhaled atmosphere by dilution with either nitrous oxide or ethylene Interference with tidal exchange with resultant hypoxia may be caused by respiratory obstruction 3) Paralysis of respiration Spinal anesthesia may produce a sufficiently high intercostal paralysis to interfere with respiration If the anesthetic agent ascends to the cervical cord diaphragmatic paralysis will follow as the result of phrenic nerve involvement

In discussing oxygen want following nitrous oxide oxygen anesthesia Courville (107) states Cerebral lesions occur primarily as a result of a triple mechanism 1) the general reduction of oxygen tension in the blood 2) a temporary cessation (or at least a marked slowing) of the blood current incident to the often attendant cardiac failure and 3) a dilatation of the small cortical blood vessels It is the last of these factors that apparently determines the localization of the early areas of cortical necrosis as

Medullary centers	20–30 minutes
Spinal cord	45–60 minutes
Sympathetic ganglia	60 minutes
Myenteric plexus	180 minutes

Certain facts now seem clear

1 The earliest evidence of a lesion is found in the perineuronal space, associated with moderate shrinkage of the nerve cell and degenerative changes in the surrounding interstitial tissues

2 The areas of focal necrosis are usually found surrounding a dilated blood vessel

3 The larger cortical lesions are but a progressive fusion of these areas of focal necrosis

If death follows immediately after acute oxygen deprivation the characteristic feature is congestion The blood vessels of the pia mater, the cortex and basal ganglia and of the choroid plexus all are dilated and filled with red blood cells Often hemorrhages may extend into nervous tissue the result of ruptured blood vessels

If death is delayed for some time following acute hypoxia, the brain will show marked damage of the gray matter

2 CHANGES DUE TO CARBON MONOXIDE POISONING

Characteristic of this condition is the formation of carboxy hemoglobin which produces the characteristic cherry red color of mucous membranes Hemorrhages when they do occur are usually petechial in type Intense congestion is the most prominent feature found at autopsy If there has been some delay between the time of exposure and of death areas of cortical softening and damage to the globus pallidus may be present The affected tissues first undergo circumscribed softening followed by depression of the areas as phagocytosis of the decadent material proceeds The globus pallidus may also show central necrosis first manifested by a circumscribed granulation of the enclosed gray matter with subsequent liquefaction and absorption

If the exposed individual recovers from the period of acute oxygen want due to carbon monoxide poisoning and survives there may often appear disturbing residuals over varying intervals of time The residuals may be of many types Visual symptoms

Blindness as a residual of anesthetic hypoxia must be extremely rare and yet Courville has had the opportunity to study three cases

1 OXYGEN WANT IN THE NEWBORN

Spasticities of childhood are the direct consequence of hypoxia at birth (108 251 255) It has been suggested that some of the other less well understood cortical degenerations of infancy and early childhood may have a similar genesis (106) Lender *et al* (152) suggest that fetal or neonatal hypoxia may play a major part in the development of epilepsy in man

The hazard of oxygen want in the fetus is becoming more generally recognized Preston (301) presents a series of 132 children in whom oxygen want due to various prenatal and postnatal causes damaged the central nervous system seriously enough to affect subsequent behavior

Persistent or fluctuating episodes of cyanosis of mucous membranes convulsive seizures or muscular twitchings a depression of spontaneous movements of the extremities or a failure to nurse properly may one or all suggest the occurrence of cerebral damage by oxygen want

Courville stresses the fact that there may be an interval between the time of acute oxygen want and the delayed appearance of residuals which may be entirely symptom free Thus many a baby who appeared at birth to be normal later in life exhibits signs of damage due to oxygen deprivation Courville (107) states that in such cases more or less constant crying occurs so much so that a large portion of the child s waking hours is so consumed This occurrence should forewarn the physician of troubles to come giving him oportunity at this early period to review critically the details of delivery which might have played a part in producing asphyxia as well as an occasion to prepare the parents for the possible unpleasant sequel

A variety of neurologic syndromes may be residual pictures of acute oxygen want in the newborn Mental deficiency may be evidenced by retarded mental development and associated slowness in sitting walking or learning to talk aimless rolling of the head from one side to another head beating and allied phenomena All are frequent residuals of oxygen want In older children the

suggested by the presence of an enlarged central vessel The congestion found at autopsy is less profound than that following other forms of oxygen want No large areas of the brain are affected

If the patient survives for a few days and then dies autopsy reveals small areas of softening in the brain which suggest those following embolism Changes in the globus pallidus are similar to those found after carbon monoxide poisoning

Residuals due to oxygen want associated with anesthesia are the result of alterations in cerebral tissues Courville states that the syndromes which have been observed as a consequence of anesthesia are

1 The acute psychoses These are seen most characteristically after nitrous oxide Emotional instability hysterical outbursts acute delirium or mania hallucinations or cataleptic states may occur as acute transitory residuals after nitrous oxide oxygen anesthesia

2 Hyperkinesias may be manifested by muscular twitchings convulsive disorders increased psychomotor activity tremors or choreiform and athetoid movements

3 Decerebrate states These are as a rule associated with profound coma and are an immediate residual more often seen after nitrous oxide The prognosis is much more grave under these circumstances but not necessarily hopeless However even with survival serious and often crippling residuals persist The patient is usually comatose Rigidity of the decerebrate type may appear This is often manifested by extensor spasm The rigidity is usually generalized but may affect the members of one side or may *alternate between the two sides*

4 The psychoneurotic states These are probably more common than has been supposed in the past If the truth were fully known it well might be that many instances of psychoneuroses are due to subclinical episodes of anoxia (107)

5 Certain chronic psychotic states It is very likely that many examples of the so called postoperative psychoses are in fact post anesthetic psychoses

6 The parkinsonian syndrome athetoid or lenticular syndromes which follow the more profound postanesthetic anoxic states are quite rare but do occur

tion with euphoria In states of survival following severe blood loss there may appear maniacal outbursts hyperkinetic and paralytic manifestations and disturbances in speech, similar to those found after other types of oxygen want These are usually transitory, and full recovery is to be expected in the majority of cases Courville (107) feels that if the shock state is prolonged however, it is possible for structural changes to occur in the cerebral cortex According to available reports these alterations are not severe and no late residuals have been noted Courville states that the possibility of mild residual symptoms in the psychic realm is to be considered It has been reported that there is increased danger from oxygen want in individuals who have lost blood (214)

9 THE ROLE OF THE SYMPATHETIC SYSTEM IN OXYGEN WANT

Sawyer and his associates (331) noted that sympathectomized cats could not tolerate oxygen want as well as could normal cats under similar conditions The sympathectomized animals could withstand an oxygen tension of 6 per cent for only 15–38 minutes whereas nonsympathectomized animals tolerated the same degree of oxygen deprivation for an hour or longer It is evident, therefore that an intact sympathetic nervous system protects the animal in its tolerance to hypoxia

SUMMARY OF EFFECTS OF HYPOXIA ON THE NERVOUS SYSTEM

Hypoxia produces an increased flow of blood to the brain This effect is augmented by increased carbon dioxide If the hypoxia is not severe the increased flow enables brain tissue to satisfy its oxygen requirements As oxygen deprivation increases the augmented flow fails to meet the requirements of the brain With injury to capillaries because of oxygen deprivation edema of the brain becomes manifest because of increased permeability of the capillaries

Of all tissues in the body the brain is most sensitive to oxygen deprivation and is the least likely to recover Characteristic changes are congestion and hemorrhage If the oxygen want has not been immediately fatal residuals either psychic or motor ap

early hypoxia may be the basis of behavior problems even in children with normal intelligence

Spastic states choreiform athetoid complex or epileptic states may appear These may or may not be complicated by mental retardation Often such is not the case and the crippled child may be bright and alert Visual syndromes and speech disturbances may also result

There also is a group in which convulsions seem to be the outstanding manifestation

5 EFFECT ON THE CEREBROSPINAL FLUID PRESSURE AND THE INTRACRANIAL PRESSURE

Oxygen want causes an increase in the cerebrospinal and intracranial fluid pressures This can be readily demonstrated during operative procedures on the brain when the patient is exposed to periods of acute oxygen deprivation Maurer (269) feels that the immediate increase in cerebrospinal fluid pressure is due to an increased cerebral blood pressure This change occurs before the blood oxygen saturation is lowered effectively

The secondary increases in the prolonged elevation of cerebrospinal fluid pressure are believed to be due to accumulation of fluid from the cerebral capillaries whose permeability is increased when blood oxygen saturation is lowered sufficiently

6 EFFECT ON THE VASOMOTOR CENTER

The acute rise in blood pressure produced by hypoxia may be the result of direct action of oxygen want on the center itself or of reflex action through the sino aortic nerves If there is any degree of carbon dioxide retention this through its central effect may cause a rise in blood pressure

7 EFFECT ON THE VOMITING CENTER

Vomiting is an early sign of oxygen want and may be due to stimulation of the vomiting center by oxygen lack

8 EFFECT ON PSYCHOLOGICAL PROCESSES

The symptoms of oxygen want are headache drowsiness pugnacity confusion and incoordination There is an early stimula

capillary bed VDM is destroyed by healthy liver tissue in the presence of oxygen and its effect is counteracted by a vasoexcitor substance produced by the kidney But a kidney inadequately supplied with oxygen does not continue to produce the excitor principle termed VEM VDM accumulates rapidly in the presence of shock and its maximum blood levels are found in irreversible shock when the capillaries show complete loss of tone and the blood cells are stationary in the lax vessels

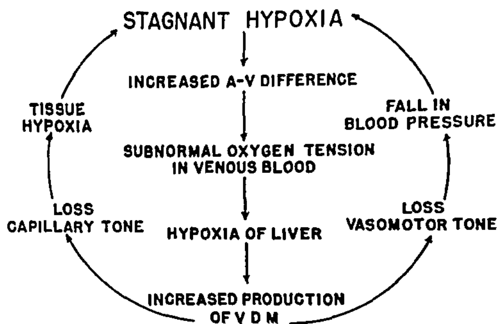


Figure 7 The vicious cycle produced by Stagnant Hypoxia with special reference to its effect on the liver

When the oxygen supply falls below maintenance levels it produces a substance which causes vascular hypo reactivity stagnation of the blood and lowered oxygen tension in the venous blood further depriving the liver of oxygen Concurrently hypoxia prevents the production of the counteracting VEM by the kidney

VDM is also excreted by the kidneys—but when its concentration is highest it cannot be eliminated satisfactorily as renal blood flow has been shown to decrease to a negligible level in shock

Stagnant Hypoxia results in an increased arteriovenous difference which is characterized by a subnormal oxygen tension in the venous blood If we are to accept the belief that 60 per cent of the

pear on return to consciousness Delayed residuals may occur as a result of fetal or neonatal hypoxia Peripheral neuritis although not a usual occurrence following oxygen deprivation, is peculiarly true of carbon monoxide poisoning

D THE EFFECT OF OXYGEN WANT ON THE LIVER

The liver is more susceptible to the effects of oxygen want than are kidney and muscle Engel *et al* (144, 145) have shown that oxygen want in the liver results in an inability of the liver to deaminate amino acids and that it also produces intrinsic damage to the hepatic parenchyma The vulnerability of the liver to damage by oxygen want seems to be due to its primary dependence on the venous blood of the portal vein to supply its oxygen

Oxygen deprivation produces a decrease in hepatic function Early in shock there is an increased uptake of oxygen from the blood by the liver with a fall in the oxygen saturation of the blood from the hepatic veins As oxygen want increases in severity the rate of oxygen uptake becomes depressed because of a decreased availability of oxygen The degree of depression of oxygen uptake by the liver is directly proportional to the degree and duration of oxygen deprivation (395) The liver is extremely sensitive to oxygen want and to reduction of its blood supply and in severe oxygen want the ability of the liver to remove bromsulphalein from the blood is reduced even in the presence of a normal arterial blood pressure (115)

Hesse (216) pointed out that the liver of aviators who died of hypoxia revealed peculiar lesions These lesions were found in the hepatic cells near the center of the lobules as large round or polyhedral vacuoles These vacuolization areas are not degenerative or necrotic changes but are the result of entrance of fluid into the liver cells from the blood due to alteration of the permeability of the walls of the hepatic cells or the walls of the sinusoids (379) This vacuolization is a reversible change and it might be defined as intracellular edema

Shorr Zweifach and their associates (351) have shown that the liver and skeletal muscles when suffering from hypoxia in shock produce a vasodepressor principle This substance termed for ease of description VDM inhibits the tone and contractility of the

resulted in a 10 per cent decrease in the adrenalin content of the adrenal glands It has been demonstrated by Lewis and his coworkers (250) that adrenalectomized animals are more susceptible to oxygen want than are normal animals The administration of adrenal cortical hormone to these animals enables them to withstand oxygen want to a greater degree than otherwise These glands therefore would seem to have an important role in protection against the hazards of oxygen deprivation In severe oxygen want there seems to be an increased activity of the sympathoadrenal system This is manifested by contraction of the spleen with hemoconcentration and an elevation of the blood sugar

G THE EFFECT OF OXYGEN WANT ON THE ALIMENTARY TRACT

In barbiturized dogs oxygen want produces inhibition of gastric motility with delay in gastric emptying time This delay in emptying time was confirmed in humans and is probably due to vagal stimulation by oxygen want with associated contraction of the pyloric sphincter This delay in gastric emptying time seems to occur also in Hemoglobic Hypoxia Anesthetic agents delay emptying time and if these anesthetic agents are used as examples of substances producing Histotoxic Hypoxia it might be said that Histotoxic Hypoxia due to these agents delays gastric motility

CHEMICAL CHANGES IN THE BLOOD DURING HYPOXIA

A EFFECTS OF HYPOXIA ON THE ACID BASE BALANCE OF THE BLOOD

In 1919 Haldane Kellas and Kennaway (195) showed that with hypoxia there occurred a diminution in the excretion of acid and ammonia with the urine becoming alkaline in reaction This bolstered the alkalosis theory The hyperventilation produced by Atmospheric Hypoxia results in increased blowing off of alveolar carbon dioxide followed by a lowering of carbon dioxide tension in arterial blood To maintain a normal acid base balance more base is secreted by the kidneys The excretion of bicarbonate by the kidney continues until the plasma bicarbonate is lowered in

oxygenation of the liver is by way of the venous blood we are thus faced with hypoxia of the liver In the presence of hypoxia there is an increased production of vasodepressor material which results in a loss of capillary tone tissue hypoxia and this in turn an added degree of Stagnant Hypoxia Vicious cycles thus become established (Figure 7)

E THE EFFECT OF OXYGEN WANT ON THE KIDNEY

Davis (115) states that it was shown by Claude Bernard that the kidneys removed a smaller proporton of oxygen from the blood than did other tissues In the presence of a low oxygen tension in arterial blood the kidneys take up oxygen in normal amounts so that the venous blood from the kidney is very low in oxygen It would seem that the kidney can tolerate considerable degrees of oxygen deprivation Van Liere (381) working with dogs showed that oxygen want is followed by a diminution in urinary output Following the period of decreased urinary output there is a period of *polyuria* *The oliguria as a result of oxygen want occurs even* under the elimination of adrenal secretion from the circulatory system and following denervation of the kidney In studies on man at high altitudes it was found that urinary output on the other hand increased Some of the work was done by Armstrong (12) in low pressure chambers and other work was done on pilots at high altitudes

Many pathologic changes appearing in the kidney have been ascribed to the ravages of oxygen deprivation These have been described by Adami (4) and by Lucke (261) Lucke found the degeneration limited to the lower segment and thus noted the development of a lower nephron nephrosis Moon (276) feels that both upper and lower segments of the kidney are involved

F THE EFFECT OF OXYGEN WANT ON THE ADRENALS

Giragossintz and Sundstroem (179) showed that rats exposed for long periods of time to low oxygen tension had necrosis and hemorrhage in the adrenal glands It was shown by Cannon and Hoskins (87) *and Schulze (338) that oxygen want though it often* stimulates the secretion of adrenalin does not always do so Emerson and Van Liere (141) pointed out that severe oxygen want

oxidative energy arising from the transformation of glycogen to lactic acid fails to meet the deficit and the sum total of energy is curtailed Due to the rapid formation of lactic acid the sum total of acid formation exceeds the normal This combined with a reduction of carbon dioxide eliminated by the lungs leads to acid accumulation in the body The resulting increase in tissue acidity further impairs oxidation and thereby sets in motion a dangerous vicious cycle (175) This vicious cycle is represented in Figure 8

In states where early oxygen want is not associated with the elimination of carbon dioxide as in rebreathing of vitiated air in a closed system, marked acidosis may occur without any intermediate alkalosis

B THE EFFECT OF OXYGEN WANT ON BLOOD SUGAR

Early in oxygen want glycosuria appears It may be due to mobilization of liver glycogen This mobilization of sugar may be due to the action of hypoxia on the central nervous system This increase in glycosuria is associated with an increased output of epinephrine There is some evidence that hyperglycemia and glycosuria are in proportion to the degree of oxygen want As the glycogen reserves of the liver are lost hyperglycemia may disappear

The hyperglycemia produced by oxygen want may in experimental animals be prevented by adrenalectomy Administration of adrenal cortical hormone to adrenalectomized animals permits a hyperglycemia to occur under oxygen want (250)

Coffee and Gellhorn (94) have shown that a period of oxygen deprivation produced 45 minutes after the subcutaneous injection of 0 25 unit of insulin per kilogram in rabbits has a more profound effect than when the drug is not given thereby causing a rise in blood sugar above the sugar level found in the insulin control experiments This would indicate that oxygen want is a more powerful stimulant to the sympathetico adrenal system in hypoglycemia than at normal blood sugar levels If however the period of oxygen want is extended over a period of two hours the hypoglycemic effect of insulin is aggravated

Gellhorn and Packer (170) in experiments on unanesthetized rabbits showed that although the inhalation of 5 4 per cent carbon

the same proportion as the carbon dioxide tension Thus, the pH changes in the blood should be very slight as long as compensation is maintained With failure of compensation alkalosis supervenes Overventilation from any cause whether due to high altitude exercise hysteria or fever or as the result of a disturbance of the respiratory center from infection of the central nervous system tumor or drugs (salicylates) may cause alkalosis

There is some evidence however that extreme degrees of oxy

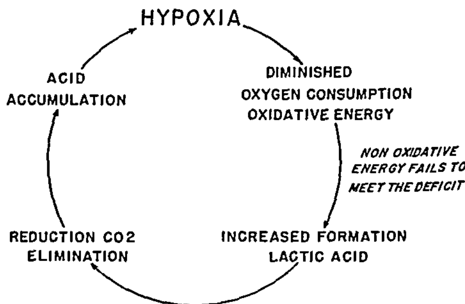


Figure 8 The tendency toward acidosis due to subnormal ventilation

gen want produce an acidosis Henderson and Radloff (212) showed that in advanced oxygen want the alkalosis may change to acidosis Acidosis increases as death approaches This is partly due to incomplete combustion of carbohydrates with lactic acid formation and to decreasing respiratory efficiency with carbon dioxide retention

Carbon dioxide alone is not the only cause for alteration in the acid base balance of the blood Gesell (173) states It is now well established that gaseous mixtures low in oxygen administered by uniform artificial ventilation diminish oxygen consumption and oxidative energy despite increased volume flow of blood Non

oxidative energy arising from the transformation of glycogen to lactic acid fails to meet the deficit and the sum total of energy is curtailed Due to the rapid formation of lactic acid the sum total of acid formation exceeds the normal This combined with a reduction of carbon dioxide eliminated by the lungs leads to acid accumulation in the body The resulting increase in tissue acidity further impairs oxidation and thereby sets in motion a dangerous vicious cycle (175) This vicious cycle is represented in Figure 8

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dioxide has practically no effect on the blood sugar when used alone, when administered in the presence of oxygen want it greatly increases the effect on the blood sugar

C BIOCHEMICAL EFFECTS OF OXYGEN WANT

Friedemann and his associates (160) showed that the lactic acid content of the blood becomes elevated in moderate hypoxia while with severe hypoxia there is a rise in both lactic and pyruvic acids Oxygen want does not seem to affect the non protein nitrogen or sodium chloride levels of the blood according to Armstrong and Heim (14) The potassium content of the blood rises in oxygen want as shown by Cattell and Civan (91) This is probably the result of the stimulating effect of oxygen want upon epinephrine secretion with a resultant passage of potassium from the liver into the blood stream (224)

MISCELLANEOUS EFFECTS OF OXYGEN WANT

A EFFECT OF OXYGEN WANT UPON BODY TEMPERATURE

Oxygen want produces a fall in body temperature Behague (61) and his co workers believe that this fall is due to diminished oxidation Gellhorn (166) feels that the degree of reduction in temperature is greatest in animals which have large surface areas The decreasing body temperature resulting from oxygen deficiency is associated with a decrease in oxygen consumption In animal experiments in low pressure chambers (166) a very marked drop in body temperature occurred within five minutes which continued to fall as the exposure to low pressures was maintained This dropping of the temperature it is felt is an important adjustment reaction since prevention of this drop in temperature almost invariably leads to death He feels that the elevation of the environmental temperature diminished the ability of the animals to withstand such oxygen deprivation

B THE EFFECT OF OXYGEN WANT UPON OXYGEN METABOLISM

Henderson and his associates (211) and Aub (15) demonstrated that traumatic shock is accompanied by a reduction in the oxygen

consumption rate Schlomovitz and his co workers (333) pointed out that blood loss did not cause a fall in oxygen consumption until an amount of blood equivalent to 1 5 to 2 5 per cent of the body weight had been lost Gesell, Blair and Trotter (171) observed that immediately after hemorrhage the consumption rate of oxygen fell to 29 per cent In similar experiments Davis (115) found the oxygen consumption rate fell from 25 to 60 per cent

PULMONARY INSUFFICIENCY

The pathologic physiology of pulmonary insufficiency has been studied by many workers Cournand and Richards (105) summarize their findings and submit a useful classification of this entity They divide pulmonary function into Ventilatory, the function concerned with the movement of air into and out of the lungs and Respiratory the function concerned with the diffusion of oxygen from alveolar spaces into the blood and the elimination of carbon dioxide from blood to alveolar air The major symptom of respiratory insufficiency is cyanosis Since the ventilatory and respiratory mechanisms are closely interrelated ventilatory insufficiency if sufficiently severe will induce respiratory insufficiency The converse is also true Respiratory insufficiency will produce increased ventilation An additional complicating factor is cardio circulatory failure as circulatory disturbances produce pulmonary symptoms

These authors for practical purposes describe four major categories of pulmonary insufficiency 1 Ventilatory insufficiency or failure of the breathing mechanics to provide the required pulmonary ventilation without dyspnea 2 Respiratory insufficiency or failure to maintain normal respiratory gas interchange between the alveoli and the pulmonary capillaries 3 Combined ventilo respiratory insufficiency and 4 Combined cardio pulmonary insufficiency of various types

A VENTILATORY INSUFFICIENCY

Inadequate ventilation is the result of a decrease in *maximum breathing capacity*, increase in *breathing requirement* or a combination of both Maintenance of a large maximum breathing capacity is dependent upon 1) an efficient neuromuscular mecha

nism of the chest cage 2) a clear pulmonary tree and 3) elastic pulmonary tissue Alteration of any of these factors results in a diminished maximum breathing capacity Of the methods to determine maximum breathing capacity Cournand and Richards recommend having the subject breathe into a spirometer and perform his maximum ventilatory effort allowing him to choose his own rate and depth The values obtained for normal males is 154 liters/min and for females 100 liters/min

Breathing requirement is the actual volume of ventilation per minute *Breathing reserve* is the excess breathing capacity beyond the actual ventilation in any given state In studies it was found that the threshold of dyspnea in the majority of cases is reached when the breathing reserve is between 60 and 70 per cent of the maximum breathing capacity

B RESPIRATORY INSUFFICIENCY

Respiratory insufficiency is the result of altered gas exchange between alveoli and blood This is dependent upon a) the proportion of functioning and non functioning alveoli b) blood flow through pulmonary capillaries, c) the gradient of pressure of respiratory gases across the alveolo capillary partition and d) physical properties of the alveolo capillary partition

The efficiency of gas exchange may be determined by measuring the volume of oxygen removed from and the carbon dioxide eliminated in each liter of air breathed

C CARDIO CIRCULATORY INSUFFICIENCY

This may be due to hypertension right heart failure, altered intrapulmonary pressures hypoxia of cardiac muscle etc

CHAPTER VI

SYMPTOMATOLOGY

A OXYGEN WANT

Oxygen deprivation sets up a train of bodily responses that are readily recognizable The signs of oxygen want however are too often overlooked and thus early treatment is neglected The signs of early hypoxia are often attributed to be the prime manifestation of the disease under treatment Oxygen insufficiency as a by effect of disease should not be overlooked The combined effects of the disease itself and the associated oxygen starvation may be too great for the patient to overcome It may be that the relief of the extra burden of oxygen deprivation might enable the patient to overcome the underlying pathology

In states of oxygen want the train of events becomes evident and it is thus possible to note the progressive appearance of symptoms The symptomatology depends to a large part on several factors

1 The speed with which the degree of oxygen want was developed
2 The mechanism of its development
3 The condition of the patient

Speed of development If the oxygen want is rapidly induced many of the early signs may be absent and the ones of advanced severity become immediately apparent

The mechanism by which oxygen lack is produced is an all important factor in the development of the symptom complex The appearance circulatory and respiratory response of a patient suffering from acute respiratory paralysis as in spinal anesthesia is completely different from that in a patient with an acute and complete respiratory obstruction The symptomatology of hypoxia in pneumonia differs from that in carbon monoxide poisoning Factors such as the presence or absence of carbon dioxide accumulation alter the respiratory and circulatory response to oxygen depriva

tion The bodily response to oxygen hunger associated with carbon dioxide retention as in partial respiratory obstruction, differs markedly from that due to oxygen hunger with carbon dioxide depletion as may occur in flights at high altitudes

The condition of the patient has a great influence upon the time of appearance and the degree of response as manifested by the signs and symptoms of hypoxia A patient with poor cardiovascular or respiratory reserve will very early even with what may not seem to be great interference with the supply of oxygen exhibit signs of advanced oxygen deficit Patients with poor cardiovascular and respiratory reserve lack the capacity to compensate by circulatory and respiratory adjustment to the added load thrown upon them

Although the symptomatology may often be confused by the speed with which the oxygen supply has been interfered with the mechanism by which it has been produced and by the patient s inability to establish the necessary compensatory means it is wise to review the symptomatology of acute oxygen deprivation

1 GRADES OF HYPOXIA

Oxygen want has been arbitrarily graded as to the severity of oxygen deprivation (325) The symptomatology to correspond is as follows

HYPOXIA GRADE I

Overconfidence restlessness nausea headache impaired judgment impaired vision dizziness weakness increased respiratory rate increased pulse rate

HYPOXIA GRADE II

Vomiting anxiety muscle incoordination twitching elevated temperature mental confusion marked increase in respiratory rate rise in blood pressure air hunger cyanosis *

HYPOXIA GRADE III

Unconsciousness convulsions slow full and bounding pulse slowing respiration irregular respiration fall in blood pressure cyanosis *

* The presence of cyanosis is dependent upon the amount of hemoglobin type of skin and the condition of the peripheral circulation

HYPOXIA GRADE IV

Coma respiratory arrest circulatory collapse asphyxia pallida

Attempts have been made to grade the degree of hypoxia as to the partial pressure of oxygen in the inhaled atmosphere (Table 3) The symptomatology will then be that of patients suffering from Atmospheric Hypoxia who had good respiratory and cardio vascular systems to begin with Patients may indeed present symp toms and signs of advanced oxygen deprivation breathing high oxygen concentrations and by the same token an occasional in dividual may tolerate moderate reduction of oxygen in the inhaled atmosphere without showing outwardly any distressing symptoms

TABLE 3

Grades of oxygen deprivation versus tension and percentage of oxygen in inhaled atmosphere

Grade Hypoxia	*pO_2 Inspired Air*	*Equivalent to Oxygen at Sea Level*
	mm Hg	*Per Cent*
1	129–99	17–13
2	106–76	14–10
3	84–53	11–7
4	68–38	9–5

2 SYMPTOMATOLOGY OF ACUTE OXYGEN WANT

a Psychic

Early in acute oxygen want there is a feeling of overconfidence and impaired judgment Impaired mental concentration and a degree of pugnacity occur frequently As oxygen lack increases in severity there often takes place an impairment of vision with dif ficulty to focus properly Anxiety is soon evident with vertigo, fol lowed by a sense of air hunger With severe oxygen lack weakness and delirium soon appear to be followed by coma

b Gastrointestinal

Nausea is an early symptom to be soon followed by retching and vomiting as the oxygen hunger becomes advanced

c Sensory

Headache is probably the most common early symptom of hypoxia Precordial pain may be a symptom of moderate degrees of oxygen insufficiency, since the coronary vessels may be unable to dilate sufficiently to allow the heart to receive its necessary quota of oxygen People with previous coronary heart disease are most likely to show precordial distress early

d Respiration

(1) **Rate** An increase in respiratory rate does not appear early The rate accelerates as the oxygen want increases in severity If the oxygen want becomes severe tachypnea is followed by a period of depression which in turn may be followed by cessation of respiration

(2) **Depth** There is very little alteration in the depth of respiration There may be a slight increase early followed by a period of depression and then cessation of respiration This pattern is of course altered if there is an associated carbon dioxide retention

(3) **Subjective reactions** In most forms of hypoxemia dyspnea is a subjective sensation The respiratory response to oxygen want is dependent upon the effect of a drop in oxygen tension on the chemoreceptors Wherein oxygen tension is decreased as in hypoxemia of Atmospheric Alveolar or Tidal Hypoxia this is apt to be a prompt symptom If there is no decrease in oxygen tension the respiratory response may be negligible Comroe and Dripps (99) note that some people become dyspneic much easier than others They state The respiratory minute volume at which dyspnea appears is about a third to a half of the total volume of air that an individual can breathe at that time by maximal voluntary effort (maximal breathing capacity) These authors stress that hyperpnea and dyspnea may occur without oxygen deprivation and that indeed oxygen deprivation may be present in the absence of dyspnea and hyperpnea

e Circulation

(1) **Blood pressure** There is a rise in the systolic pressure As the oxygen hunger increases in severity the blood pressure con

tinues to rise and as the oxygen dearth increases the rising blood pressure becomes reversed and falls acutely to be followed by cessation of cardiac activity Gellhorn (167) states The significance of respiratory response to anoxia is evident from the fact

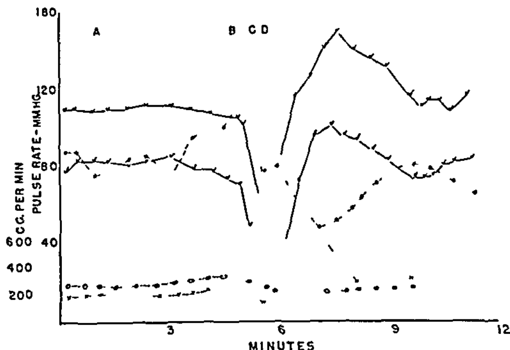


Figure 9 Acute oxygen deprivation (From Exhibit on Anesthesia Scientific Exhibit San Francisco Session 1938)

Blood Pressure √ √ Pulse rate Respiratory rate o o Tidal volume x x The column of figures on the extreme left represents tidal volume in cubic centimeters The second column of figures represents blood pressure in millimeters of mercury and pulse and respiratory rates per minute

A woman 25 years old following 35 minutes of nitrous oxide anesthesia for a minor pelvic operation *was caused to inhale pure nitrous oxide through an* endotracheal airway from a recording spirometer for approximately five minutes (A D) At B the pulse was weak color only slightly cyanotic At C the blood pressure could not be read At D respiration had almost ceased The chest was then inflated twice with pure oxygen After a period of apnea lasting 30 seconds note the rise in blood pressure and tidal volume and the decrease in pulse rate Premedication (Morphine gr 1/8 Scopolamine gr 1/200 and Paraldehyde oz 1 in this case) frequently thus modifies the typical oxygen crisis seen in laboratory animals subjected to acute oxygen want

that when the respiratory response is poor the blood pressure rise is marked but that no elevation in blood pressure may occur when an adequate increase in respiration is observed The rise of blood pressure is due to stimulation of the chemoreceptors of the carotid

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e Circulation

(1) Blood pressure There is a rise in the systolic pressure As the oxygen hunger increases in severity the blood pressure con

may be observed when the arterial oxygen saturation falls to 85 per cent In patients with anemia changes in color may not be evidenced until the arterial oxygen saturation has fallen to below 75 per cent Indeed if the degree of anemia is sufficiently great death from oxygen want may ensue without cyanosis ever having become evident This is also true in carbon monoxide or cyanide poisoning Another important factor in the appearance of cyanosis is the state of the capillary circulation If marked capillary con striction is present cyanosis may not appear even in the presence of a marked increase in the amount of reduced hemoglobin This is the reason why cyanosis is not a prominent characteristic of shock

Much work has been done in correlating arterial oxygen satura tions with clinical impressions of cyanosis in patients Comroe and Botelho (97) stress how difficult it is to use cyanosis as an indica tion of the degree of arterial hypoxemia They employed the oxi meter to review previous work and determined that cyanosis de pends not only on variables in the patient but also upon variables in the observers They are convinced that cyanosis is a poor index for the degree of arterial desaturation if it is slight or moderate The variables which may modify the perception of cyanosis are (a) the thickness color and opacity of the skin (b) the number and length of blood filled capillaries in a given surface area and the state of these vessels whether dilated or constricted (c) variations in the color of the plasma caused by dyes or drugs and (d) varia tions in the type color and amount of hemoglobin (presence of methemoglobin sulfhemoglobin or carboxyhemoglobin)

In the majority of cases it was shown that arterial desaturation is probably unrecognized until the saturation has dropped to about 85 per cent On occasion it is not recognized even at 70 to 75 per cent levels

A less important factor is the amount of carbon dioxide in the blood Carbon dioxide has a dual effect on vascular tone By its central action is causes vasoconstriction and peripherally its effect is vasodilation An increased carbon dioxide tension in the blood particularly in stagnant areas may lead to dilation and thus make the presence of reduced hemoglobin evident by cyanosis

sinus and the arch of the aorta since after their removal the blood pressure falls in anoxia even when artificial respiration is used

(2) Pulse rate The pulse rate becomes elevated and if the acute oxygen want is great and rapid, the pulse may for a while become slow, full and bounding The pulse rate may increase in the presence of a reduction in arterial oxygen tension which is insufficient to stimulate respiration An increase in the pulse rate will follow a reduction in the total arterial oxygen content even if the pO_2 is normal Comroe and Dripps (99) have shown that in those forms of oxygen want in which there is a reduction in both arterial oxygen tension and oxygen saturation the pulse rate increased 4 per cent at 93 per cent saturation 10 per cent at 80 per cent saturation and 30 per cent at 72 per cent saturation In those clinical conditions in which there is a decrease in arterial oxygen content but with a normal oxygen tension tachycardia occurs despite the failure of respiration to increase In one series the pulse rate of the normal group was 68 and rose to 79 in anemic patients with a hemoglobin of 7–13 grams and to 88 in the group with a hemoglobin below 7 grams Since the arterial pO_2 is normal this tachycardia is not expected to originate in chemoreceptor reflexes It may be due to vasomotor stimulation because of the low oxygen content

The effect of acute oxygen deprivation on the blood pressure, pulse rate respiratory rate and minute volume exchange are shown in Figure 9

f Muscular

As the oxygen want increases in severity there occurs muscular incoordination with twitching to be followed by convulsions A period of muscular relaxation appears before death

g Color

Cyanosis is an unreliable sign of the extent of oxygen want Its appearance is due to reduced hemoglobin in the capillary blood A minimum of five grams of reduced hemoglobin for each 100 cubic centimeters of blood is required to make a color change visible in the skin In an otherwise normal individual cyanosis

may be observed when the arterial oxygen saturation falls to 85 per cent In patients with anemia changes in color may not be evidenced until the arterial oxygen saturation has fallen to below 55 per cent Indeed if the degree of anemia is sufficiently great, death from oxygen want may ensue without cyanosis ever having become evident This is also true in carbon monoxide or cyanide poisoning Another important factor in the appearance of cyanosis is the state of the capillary circulation If marked capillary constriction is present cyanosis may not appear even in the presence of a marked increase in the amount of reduced hemoglobin This is the reason why cyanosis is not a prominent characteristic of shock

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h Eyes

As the oxygen severity increases, the pupils become dilated The eyeball may often be fixed with the pupil eccentric usually facing upward

3 CHRONIC HYPOXIA

a Symptomatology

People living in high altitudes have been the subjects of investigations to determine the alterations due to long periods of oxygen deprivation The symptomatology of oxygen deprivation over long periods of time is dependent a good deal upon the individual s ability to compensate People living in high altitudes for long periods of time not only can compensate by alterations in their circulatory and respiratory systems but they learn to limit their work at this altitude

b Effect on the Blood

It has been shown that there is macrocytosis reticulocytosis polycythemia and increase in hemoglobin increase in platelets a decreased coagulation time an increased oxygen capacity and an increased affinity of hemoglobin for oxygen with a shift of the oxygen dissociation curve to the left

c Effect on the Heart and Circulation

After acclimatization the pulse rate begins to return to normal Blood pressure is usually unaltered If the state of chronic oxygen want has been sufficiently great there may be some associated cardiac damage as a result of which the blood pressure may be lowered There has been some evidence to show that in some instances there is some cardiac dilation and in others cardiac hypertrophy

B CARBON DIOXIDE EXCESS

The symptomatology of carbon dioxide excess should be known to anyone interested in oxygen inadequacy and its treatment For not only may carbon dioxide excess occur in disease associated with the oxygen scarcity but the hazards of producing carbon

dioxide excess in attempting to achieve oxygen purity are great Many of the methods employed for oxygen administration are confined extensions of the respiratory tract with the result that there is an increase of dead space on a mechanical basis Such space serves as a reservoir for carbon dioxide accumulation Better design of apparatus is rapidly overcoming this unfortunate situation Carbon dioxide retention, however, is an ever present possibility in most of the therapeutic measures employed to treat hypoxia by inhalation Further the administration of carbon dioxide even as high as 30 per cent in oxygen, has been recommended for a wide variety of conditions The inhalation of up to 5 per cent carbon dioxide may be tolerated by the patient but 5 to 10 per cent is intolerable 20 to 30 per cent is sub anesthetic 30 to 40 per cent is anesthetic and over 40 per cent may be fatal (183)

1 PSYCHIC

Early in inhalation of excess amounts of carbon dioxide one is impressed with the discomfort associated with increased respiration Dizziness soon follows afterwards with loss of consciousness

2 SENSORY

There is very little sensory disturbance unless the percentage of carbon dioxide is very great With increasing concentrations the patient is conscious of hypercapnea Many complain of this feeling If the concentrations are great enough to induce semi consciousness these patients may have dreams or hallucinations Some patients complain of seeing things under the influence of carbon dioxide—colored lights colored dots persons and things moving in circles (271) On occasion if the concentrations are great enough the patients black out and remember very little of what happened to them

3 RESPIRATION

a Rate

There may be very little increase in rate at any time with carbon dioxide excess As the excess increases the respiratory rate decreases and then respiration may cease

h Eyes

As the oxygen severity increases, the pupils become dilated The eyeball may often be fixed with the pupil eccentric usually facing upward

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poxia If the oxygen deprivation is sufficiently great the respiratory center is rendered completely insensitive to carbon dioxide and thus the respiratory pattern will be that of hypoxia alone

Normally pulmonary ventilation is increased by the addition of but one per cent carbon dioxide As the concentration of the administered carbon dioxide is increased ventilation increases to a maximum value of 60 to 70 liters per minute (a tenfold increase over resting value) This maximum increase is reached with about 9 per cent carbon dioxide in the inhaled atmosphere At about 10 per cent the narcotic effect becomes evident and with increasing percentages ventilatory response is gradually diminished and soon becomes convulsive in character At about 30 per cent ventilation may be close to normal At 40 per cent ventilation is depressed below normal and fatality may occur

4 BLOOD PRESSURE

The systolic blood pressure is markedly increased and as the carbon dioxide excess continues the blood pressure continues to rise until with increasing carbon dioxide tensions the blood pressure falls

5 PULSE RATE

There is an early rise in rate and as the toxicity increases the rate becomes more rapid

The effect of acute carbon dioxide accumulation on the blood pressure pulse rate respiratory rate and minute volume exchange is shown in Figure 10

6 MUSCULAR

There is an early twitching of muscle groups followed by spasms and then convulsions

7 COLOR

The patient may be of good color due to peripheral dilatation of the blood vessels

8 PUPILS

The response is variable

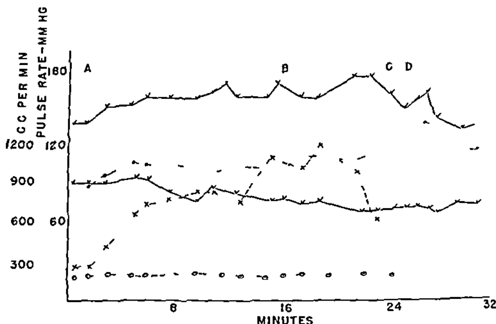


Figure 10 Acute carbon dioxide accumulation (From Exhibit on Anesthesia Scientific Exhibit San Francisco Session September 1938)

Blood pressure ✓ ✓ Pulse rate Respiratory rate o o Tidal volume x x The columns of figures on the extreme left represent tidal volume in cubic centimeters The second column of figures represents blood pressure in millimeters of mercury and pulse and respiratory rates per minute

A woman 26 years old following 70 minutes of nitrous oxide anesthesia for arthrodesis of the ankle was caused to rebreathe a nitrous oxide-oxygen mixture through an endotracheal airway from a recording spirometer without soda lime for a period of approximately 24 minutes (A C) At B some oxygen was added somewhat reducing the carbon dioxide concentration which had accumulated At C the rebreathing was discontinued and the patient allowed to breathe air No spirometer record was obtained from this point At D the patient was awakening Note the rise in systolic blood pressure and pulse rate and the extreme rise in tidal volume while the respiratory rate was only slightly increased The beginning depression characteristic of increasingly high carbon dioxide concentrations is seen in the fall in tidal volume at the end The premedication in this case was Morphine gr 1/4 and Scopolamine gr 1/100

b Depth

The most marked response to carbon dioxide excess is an increased amplitude of respiration This increase is evident early followed by a period of depression and then cessation The extent of respiratory response is to a large degree dependent upon the state of irritability of the respiratory center The respiratory threshold is elevated and its degree of irritability lessened by hy

cubic centimeter of this being physically dissolved in the plasma. The venous blood (B) is at an oxygen tension of 40 millimeters of mercury and its content is about 14 volumes per cent.

Were a normal individual to inhale 100 per cent oxygen, the tension in the arterial blood would increase to over 500 millimeters of mercury; the hemoglobin becomes 100 per cent saturated

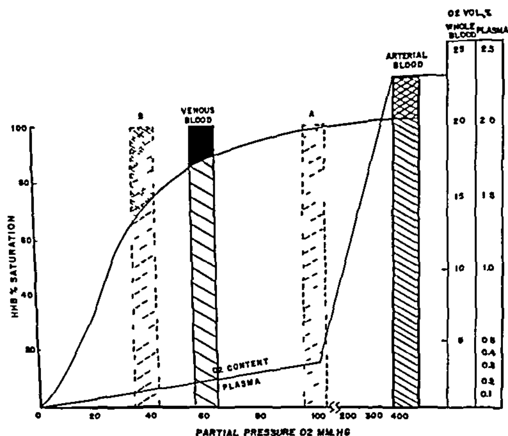


Figure 11. The effect on blood values of the inhalation of high oxygen atmospheres by the normal individual.

rated and the arterial oxygen content increases to about 23.5 cubic centimeters per 100 cubic centimeters. Of this increase about 0.5 cubic centimeter is due to an increased combination with hemoglobin and the rest is due to the increase in physically dissolved oxygen. The plasma now contains about 2.3 cubic centimeters per 100 cubic centimeters of blood. Since no more oxygen is removed the A-V difference remains normal and the venous blood therefore contains more oxygen. The hemoglobin saturation of mixed

CHAPTER VII

THE EFFECTS OF THE INHALATION OF OXYGEN

A OXYGEN TRANSPORT

To UNDERSTAND and employ oxygen rationally in the various forms of hypoxia it is essential that one be familiar with the oxygen dissociation curve (Figure 2) This curve shows the relationship between the partial pressure of oxygen and the percentage saturation of hemoglobin, that is, the ratio between reduced and oxygenated hemoglobin It will be noted that at 100 millimeters of mercury, hemoglobin is about 95 per cent saturated Since the upper part of the curve is flattened out an increase in tension to more than 100 millimeters of mercury can increase the percentage saturation but 5 per cent A reduction in arterial oxygen tension however to about 70 millimeters of mercury will still leave the hemoglobin 90 per cent saturated Since the mid portion of the curve is more nearly vertical a fall in oxygen pressure results in a very great desaturation of hemoglobin Thus in those states of hypoxia where the tension of oxygen in blood is low removal of but small amounts of oxygen will result in a marked desaturation of the hemoglobin

The curve may be altered by a change in the pH of blood A change toward the acid side will cause the curve to flatten toward the right indicating a reduction in the affinity of hemoglobin for oxygen Carbon dioxide increase exerts this effect This is known as the Bohr effect An increase in temperature also causes a shift in this same direction Alkalosis a decrease in pCO_2 and a drop in temperature have an opposite effect

Normally (Figure 11) the arterial blood (A) is at a tension of 100 millimeters of mercury The hemoglobin is 95 per cent saturated and the oxygen content is about 19 5 volumes per cent 0 3

the administration of oxygen the arterial oxygen content is markedly increased because of an increased percentage saturation of the hemoglobin and an increase in the physically dissolved oxygen Because of this marked increase in the arterial oxygen content, percentage saturation and tension the tissue needs are more readily met and a greater availability of oxygen to tissue is present

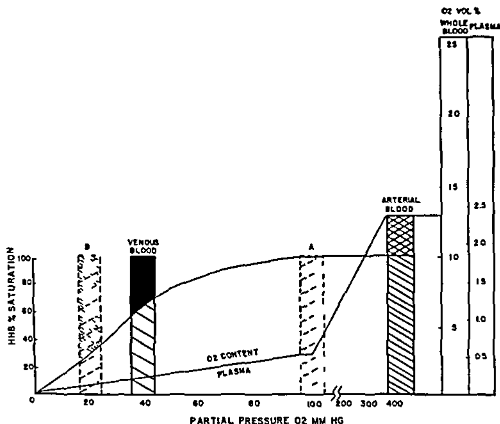


Figure 13 The effect on blood values of the inhalation of high oxygen atmospheres by individuals suffering from Hemoglobic Hypoxia

The venous blood is not nearly so desaturated and the oxygen available to tissue therefore is much greater than was the case before oxygen administration In this particular instance the head of oxygen pressure in tissues as reflected in venous blood is elevated from 20 to about 35 millimeters of mercury

Hemoglobic Hypoxia (Figure 13) In this form of oxygen want in the arterial blood (A) the arterial oxygen tension is normal—100 millimeters of mercury In the example given, however the arterial oxygen content is markedly decreased because of the in

venous blood is at about 80 per cent and the partial pressure of oxygen is at 60 millimeters of mercury It is important here to note that as a result of breathing 100 per cent oxygen there is a 50 per cent increase in the partial pressure of oxygen in venous blood over the normal

Before one can review the effect of oxygen inhalation in the various forms of hypoxia, it is important to be familiar with the

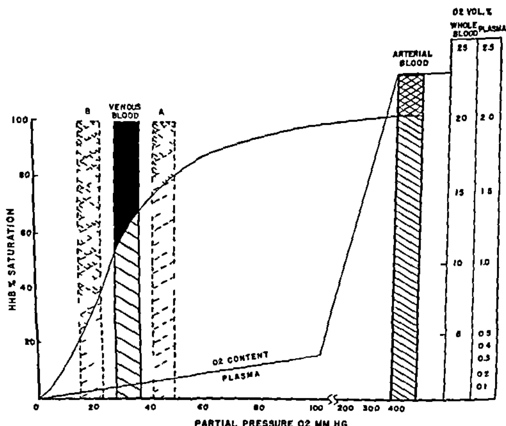


Figure 12 The effect of the inhalation of high oxygen atmospheres by patients suffering from Atmospheric Tidal or Alveolar Hypoxia

oxygen capacity the arterial oxygen content and tension the venous oxygen content and tension and the A V difference in the various forms of hypoxia These are summarized in Table 2

Atmospheric Tidal and Alveolar Hypoxia (Figure 12) The arterial blood (A) shows a decrease in oxygen content percentage saturation and pO The venous blood (B) shows a similarly marked decrease The arteriovenous difference is decreased With

the order of about 18 millimeters of mercury There is a wide A V difference and the percentage desaturation is great The administration of oxygen in this form of oxygen want results in an increase almost entirely due to an increase in physically dissolved oxygen In this instance the increased head of pressure results in a better oxygen uptake by tissue but because of a stagnant cir

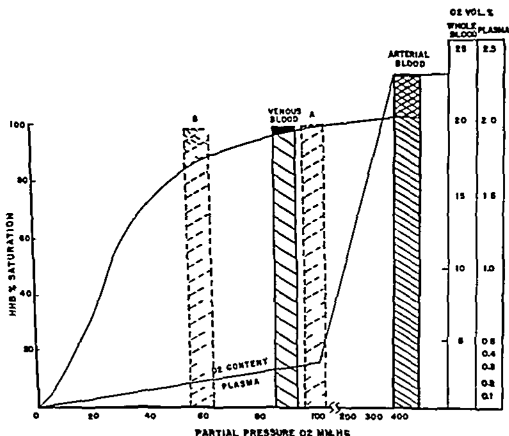


Figure 15 The effect on blood values of the inhalation of high oxygen atmospheres by individuals suffering from Histotoxic Hypoxia

culation there will still be a marked desaturation of the venous blood However the consequent increase in the head of pressure because of the inhalation of oxygen is of value

Histotoxic Hypoxia (Figure 15) Here too the arterial oxygen tension is normal and the arterial oxygen saturation is normal as is its content The venous blood (B) however is at a high tension and a high percentage saturation because of an inability of tissue to take up oxygen Consequently the A V difference is decreased

ability of blood to carry oxygen and is at about 10 volumes per cent The venous blood (B) is at a low tension The saturation is at about 35 per cent and there is an extremely low oxygen content The administration of oxygen here increases the amount of oxygen available to tissue by about 2½ volumes per cent, mainly through the increased saturation of the plasma The increase in

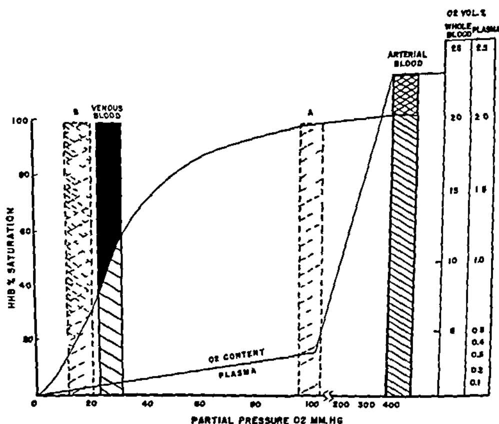


Figure 14 The effect on blood values of the inhalation of high oxygen atmospheres by individuals suffering from Stagnant Hypoxia

oxygen in this instance in the arterial blood is on the order of 25 per cent In the venous blood (B) the tension is at about 40 millimeters of mercury and here it is noted that the administration of oxygen in the presence of Hemoglobic Hypoxia may increase the head of pressure in the venous blood by 100 per cent

Stagnant Hypoxia (Figure 14) In this form of oxygen want the arterial blood (A) is at a tension of 100 millimeters of mercury The venous blood (B) however is at an extremely low tension on

the venous blood consequently contains a greater amount of oxygen. The percentage saturation is increased and there is a marked increase in head of pressure to tissues.

B. CARBON DIOXIDE TRANSPORT

An increased saturation of hemoglobin by the inhalation of high oxygen atmospheres may have a deleterious effect on the transport of carbon dioxide. Hemoglobin when reduced has greater ability to take up the carbon dioxide from tissue than it does when oxygenated. If hemoglobin is more saturated than normal, less carbon dioxide will be picked up and brought to the lungs for elimination. Theoretically then, saturation of plasma with oxygen will allow for less dissociation of hemoglobin and thus a diminished efficiency for carbon dioxide removal. It is thus possible that tissue acidosis may be encouraged.

C. EFFECT ON CIRCULATION

High concentrations of oxygen have a circulatory effect even when the patient is not suffering from oxygen hunger. The pulse rate drops. This may be the result of the high oxygen tension acting on the carotid body mechanism. On occasion, the decreased pulse rate may be so great as to result in bradycardia. Because of a decrease in both cardiac rate and stroke volume the cardiac output drops. The change in systolic blood pressure is not remarkable. The inhalation of 100 per cent oxygen is said to be followed by a diminution in coronary blood flow.

The direct action of high oxygen concentrations upon the systemic blood vessels is one of constriction. This constriction is sufficient to overcome the vasodilating effect on these vessels produced by reflex action through the chemoreceptors. The cerebral vessels are affected differently (334). High oxygen concentrations tend to reverse the normally present vasodilation of these vessels by producing some degree of vasoconstriction with a concomitant reduction in cerebral blood flow. Hyperoxygenation dilates pulmonary vessels reversing the constricting effects of hypoxemia.

D. EFFECT ON RESPIRATION

There may be no immediate respiratory response to the inhalation of high oxygen concentrations by a normal individual or the

The administration of oxygen in this instance results in an increase in the oxygen content of arterial blood almost entirely due to an increase in physically dissolved oxygen In spite of this increase in arterial oxygen availability the A V difference is not improved because of inability of tissue to utilize oxygen The venous blood is consequently very highly saturated with no particular benefit to tissue

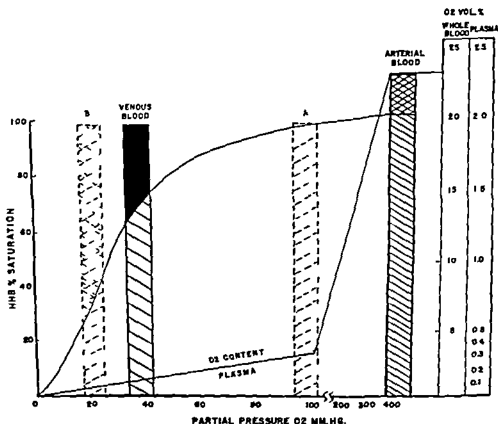


Figure 16 *The effect on blood values of the inhalation of high oxygen atmospheres by individuals suffering from Demand Hypoxia*

Demand Hypoxia (Figure 16) In this form of oxygen deprivation the arterial oxygen tension percentage saturation and content are normal However because of increased tissue needs the venous blood (B) shows marked desaturation and marked decrease in partial pressure An increase in the oxygen content by the inhalation of oxygen is due to an increase in the percentage saturation and also an increase in the physically dissolved oxygen Because of increased availability of oxygen tissue needs may be better met and

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D EFFECT ON RESPIRATION

There may be no immediate respiratory response to the inhalation of high oxygen concentrations by a normal individual or the

depression in minute volume exchange may be slight With continued breathing of high oxygen atmospheres some degree of respiratory stimulation appears with an increase in minute volume exchange Comroe and Dripps (99) give six possible explanations for this phenomenon 1 The inhalation of oxygen leads to an increase in carbon dioxide tension of tissues, including the medullary respiratory centers with an increase in respiration 2 High oxygen concentrations may be an irritant to the lower respiratory tract and thus set up reflexes which increase respiration 3 Oxygen inhalation may be followed by the collapse of enough alveoli to set up vagal response 4 Oxygen may cause the cerebral vasoconstriction which leads to an accumulation of metabolic carbon dioxide in the brain including the respiratory center 5 High oxygen tension leads to improved function of the respiratory center 6 Oxygen dilates the pulmonary capillaries and may produce reflex respiratory stimulation as the result of slight pulmonary congestion

E. MENTAL CHANGES

Mental changes have been noted in patients suffering from chronic hypoxemia when oxygen was administered (29 113 122 180) These patients have become irrational stuporous and even comatose In some an uncontrollable myoclonic movement in the arms appeared In general the patients regained consciousness rather rapidly when the high oxygen atmosphere was removed Some however did not regain consciousness and died

Comroe *et al* (96) noted similar changes and studied 65 patients *suffering from chronic oxygen want to whom oxygen was administered* Of these 65 mental changes appeared in eight There seemed to be no doubt but that some chronically hypoxemic patients become somnolent or even comatose during the administration of 100 per cent oxygen They state that this reaction occurs infrequently and serious consequences are rare and that the reaction thus appears to be limited to patients who have pulmonary insufficiency for both oxygen and carbon dioxide They consider the several possible mechanisms for the production of these mental changes

1 CARBON DIOXIDE NARCOSIS

Because oxygen therapy in these patients reduces chemoreceptor activity and thus diminishes the minute and tidal volume of respiration the resultant depression of respiratory activity results in poor elimination of carbon dioxide and its accumulation in the blood and body tissues Such accumulation of carbon dioxide may on occasion be sufficient to produce unconsciousness It might be that chronically hypoxic patients are more susceptible to the depressing effects of high concentrations of carbon dioxide

2 CEREBRAL VASOSPASM

Hypoxia it is known dilates the cerebral blood vessels and increases cerebral blood flow It is theoretically possible that by the inhalation of 100 per cent oxygen constriction or even spasm of cerebral blood vessels may occur and thus precipitate coma

3 REFLEX DEPRESSION OF CEREBRAL CORTEX BY HIGH OXYGEN TENSION

Comroe *et al* (96) state Anoxemia by reflex action stimulates the cerebral cortex as well as the vasomotor and respiratory centers The restlessness and delirium associated with anoxemia are probably manifestations of this effect High oxygen administration may thus result in withdrawal of this cortical stimulation and lead to coma

4 INCREASED CEREBROSPINAL FLUID PRESSURE

It had been noted by Simpson (354) and Davies and Mackinnon (113) that *there is an increase in cerebrospinal fluid pressure in* patients with cor pulmonale They found that the pressure usually increases during inhalation of oxygen The authors note that this increase in cerebrospinal fluid pressure may be associated with and actually caused by cerebral vasodilation due to retention of carbon dioxide

5 DIRECT DEPRESSION OF THE CEREBRAL CORTEX BY HIGH OXYGEN TENSION

Patients with chronic oxygen want may have alterations of a compensatory nature in cerebral metabolism Sudden removal of

these may lead to inability to utilize oxygen at normal or high pressures followed by loss of consciousness

F OXYGEN POISONING

Both Paul Bert and Lavoisier (163) noted toxic effects due to the inhalation of high oxygen atmospheres Some of these harmful effects may be ascribed to the presence of increased carbon dioxide pressure in tissues associated with the inhalation of high oxygen concentrations over long periods of time since oxyhemoglobin is more acid than reduced hemoglobin and carbon dioxide there fore, is less readily removed High oxygen pressure slows circula tion by diminution of the heart s action or by constriction of cerebral vessels to protect the brain from the too high an oxygen pressure (194) A pressure of oxygen equal to one atmosphere does not increase but rather decreases the processes of oxidation (219)

Animal experimentation by J Lorraine Smith (361) showed that pneumonia developed after inhalation of high oxygen concentra tions for four days Congestion edema epithelial desquamation and finally a fibrinous bronchopneumonia were observed

Kaunitz (228) exposed mice to 100 per cent oxygen at atmos pheric pressure for 72 hours Most of the animals died during this period Examination of the respiratory tract showed changes com parable to those found after exposure to phosgene Death of the animals was attributed to oxygen want

Binger *et al* (68) kept rabbits in an atmosphere of approxi mately 80 per cent oxygen for eight days after which the animals were sacrificed Autopsy revealed marked capillary engorgement with hemorrhage interstitial and alveolar exudate hypertrophy and desquamation of alveolar walls and infiltration of mononuclear cells The experiments demonstrated that inhalation of oxygen in concentrations greater than 70 per cent may lead to a train of physiological changes consisting of drowsiness loss of appetite loss of weight dyspnea and cyanosis usually culminating in death from extreme oxygen want The cause of the oxygen want is undoubt edly to be sought for in the acute pulmonary changes character ized as a diffuse hemorrhagic edema of the lungs found in all these species

Barach (27) states Although animals regularly develop edema

of the lungs after three to four days inhalation of atmospheres containing 80 to 100 per cent oxygen human beings *appear* to be able to tolerate these high concentrations without harm for at least two days and possibly for as long as one week He states further that the administration of oxygen in concentrations under 70 per cent may be continued indefinitely

Much of the toxic response in animals has been confirmed in humans exposed to atmospheres with high oxygen content Behnke (62) revealed that healthy men between the ages of 20 to 40 are unable to breathe 99 per cent oxygen for periods in excess of seven hours because of nausea, dyspnea and substernal soreness Becker Freyseng and Clamann (57) reported the results of studies wherein two men breathed 99 per cent oxygen for 65 hours Reduction in vital capacity occurred in both One developed nausea repeated vomiting tachycardia afebrile tracheobronchitis dyspnea and pain in elbows and knees

Whitehorn *et al* (390) administered pure oxygen to normal men and observed a lowering of cardiac output as determined ballistocardiographically

Boothby *et al* (72) reported no untoward effects to breathing high oxygen concentrations over protracted periods It is difficult to accept this in its entirety because of the conditions upon which the conclusions are based A face mask was used which was undoubtedly removed at intervals for feeding nursing and medication The B L B (Boothby Lovelace and Bulbulian) mask cannot deliver 100 per cent oxygen with the reduced pressure system ordinarily employed The flow is inadequate Not only may air enter about the face piece but the apparatus is so designed that air is sucked in through sponge rubber discs when there is not enough oxygen in the rebreathing bag to satisfy a tidal effort

Comroe *et al* (100) determined the effects of breathing high concentrations of oxygen in humans because of the rather recent introduction and widespread use of apparatus designed for this purpose They studied the effects of 98 to 99½ per cent oxygen on a number of men for a 24 hour period An oxygen hood was used on six subjects employing complete circuit rebreathing and carbon dioxide absorption A possible factor in the results produced in these subjects may be the higher than normal carbon dioxide

concentration present in the hood because of the relative inefficiency of agents used to absorb carbon dioxide In 84 subjects oxygen was administered through a demand system Here too a factor was introduced which though seemingly unimportant may have a bearing on the results A demand system is one wherein oxygen delivery is initiated by the effort of inspiration The degree of negative pressure required to actuate the delivery may of itself be sufficiently great to cause untoward effects if long continued

The work of Comroe *et al* is an important one on this aspect and it has a sufficiently important bearing on the use of high oxygen concentrations clinically to be quoted at some length in the following

SYMPTOMATOLOGY FROM INHALATION OF 100 PER CENT OXYGEN

Substernal distress was complained of by four of six subjects in the hood and 24 of 28 subjects wearing masks Sensations were described as felt as though I had been smoking excessively as though breathing raw cold air, as though I had just run a race to the point of exhaustion felt like bronchitis The substernal distress was noted at an average time of 14 hours after start of the oxygen, the range being from four to 22 hours This distress was never severe enough to necessitate discontinuance of the experiment before the end of the 24 hour period In experiments to determine the percentage of oxygen required to produce substernal distress subjects were exposed to various percentages for 24 hours The results of these authors showed that the concentrations required to produce substernal distress in normal men lies between 50 to 75 per cent and probably is close to 60 per cent

Cough, sore throat and *nasal congestion* appeared in a considerable number of the subjects investigated Forty three per cent developed nasal congestion or coryza Thirty two per cent developed sore throat and 54 per cent had occasional or repeated cough In a control group breathing air under conditions similar to the subjects breathing oxygen a comparable percentage developed throat irritation It would thus seem that the conditions of the experiment rather than the oxygen concentration produced this complication

Eye irritation occurred in 23 per cent of the subjects breathing 100 per cent oxygen and in 10 per cent of those breathing room air

Lower respiratory tract damage was a constant finding in the animal experimentation previously spoken of The substernal distress evident in this experiment may point strongly to the existence of alveolar damage The authors determined vital capacities in the subjects before and after the experiment Of 80 subjects breathing high oxygen concentrations 63 showed a *decreased* vital capacity In 38 subjects the diminution in vital capacity amounted to more than 200 cubic centimeters in 26 more than 300 cubic centimeters, and in 13 to more than 400 cubic centimeters In two instances the maximum decrease was 1480 cubic centimeters The cause of this reduction is not certain The decrease in vital capacity seems to have had no relationship to the severity of the substernal distress X rays revealed no atelectasis nor any other pulmonary abnormality

Ear discomfort appeared in 25 per cent of those inhaling 100 per cent oxygen This is probably due to absorption of gas from the middle ear

Fatigue was also reported in 25 per cent of those inhaling 100 per cent oxygen continuously and by 10 per cent of those inhaling air

Comroe *et al* (100) on the basis of the 24 hour experiments believe that if such inhalation therapy had been prolonged over two three or four days severe pulmonary congestion and edema would have resulted

Evans (147) believes that inhalation of 100 per cent oxygen cannot be harmful to a patient suffering oxygen want because of the presence of increased pulmonary transudate or exudate which prevents the high tension of oxygen from reaching the alveolar membrane This may be so However only the damaged alveoli or that area of the lung protected by exudate would be saved from the harmful effects of high oxygen Areas unprotected could still be irritated as may be the tracheobronchial tree In the matter of the presence of pulmonary transudate Drinker (127) believes that the use of 100 per cent oxygen can actually aid in the resorption of pulmonary transudate This should be true only when the pulmo

nary edema is due primarily to severe oxygen lack with a resulting increase in capillary permeability In such instances 100 per cent oxygen would tend to reverse this process, at least initially

Drinker (128) re affirms Paul Bert s observation that pure oxy gen under high pressure will cause epileptic convulsions How ever, the pressure of oxygen which will produce convulsion is so extreme as not to be encountered clinically On the other hand there seems to be no doubt that the continued inhalation of 100 per cent oxygen at normal barometric pressures for six hours will cause irritation of the respiratory passages This irritation is a mild but progressive inflammation which is fortunately easily pre vented

Campbell and Poulton (86) state that it would be unsafe to expose a patient with pneumonia cardiac failure etc for a long period to a percentage of oxygen above 60 but that 50 to 60 per cent is safe For short periods, however, as in the treatment of car bon monoxide poisoning pure oxygen may be used

One hundred per cent oxygen may be given with safety to all patients with hypoxia for short periods (100) When oxygen ther apy must be continued beyond a 12 hour period the concentration should be decreased to 50 to 60 per cent unless this is insufficient to oxygenate arterial blood properly Arterial unsaturation rep resents more of a threat to the patient s life than does the possibil ity of a tracheobronchitis due to oxygen One hundred per cent oxygen should be used for long periods only when lower concen trations fail to saturate the blood When high concentrations of oxygen are used for protracted periods of time the physician in attendance should question the patient at frequent intervals in re gard to substernal distress especially following deep breathing or upon removal of the oxygen therapy equipment

A factor which was not considered in the work of Comroe *et al* (100) and which may have a bearing on the tracheobronchitis is the dehydrating effect of oxygen Hulpieu and Cole (225) showed that both high temperature and low humidity are more conducive to oxygen poisoning than the reverse In the apparatus used by Comroe *et al* particularly in the demand type no mention was made of humidification of the inspired oxygen It may be that

much of the substernal distress due to tracheobronchitis may be due to dehydration of the tissues

Ohlsson *et al* (289) exposed continuously six healthy young men for 53 to 57 hours to an oxygen concentration of 78 to 88 per cent with control of carbon dioxide content, relative humidity and external temperature Four out of the six men were affected by substernal distress Five showed a decrease in their vital capacity The disturbance in the blood carriage of carbon dioxide which occurs in the inhalation of oxygen in high concentrations is the principal factor in the causation of pulmonary damage and oxygen poisoning and the pulmonary damage is not produced by a direct irritant effect from the air side but by the above mentioned indirect effect from the blood side Pulmonary damage is unlikely in connection with long continued *clinical* treatment with oxygen in high concentrations Toxic effects in healthy subjects if they do occur are reversible

SUMMARY

Because of marked arterial desaturation of hemoglobin in Atmospheric Tidal and Alveolar forms of hypoxia the administration of oxygen to patients suffering from these forms of oxygen want will result in the greatest increase in arterial oxygen content Because of this these forms of hypoxia are most amenable to therapy

The benefit to be gained by the administration of oxygen to patients suffering from Hemoglobic Stagnant or Demand Hypoxia is because of saturation of the plasma with oxygen The benefit derived therefrom is definite but it is not nearly as satisfactory as for the conditions first mentioned

In Histotoxic Hypoxia the arterial oxygen content is elevated by inhalation therapy but probably to no real avail for the hypoxic state is the result of the inability of tissue to utilize oxygen

The inhalation of high oxygen atmospheres is not without disadvantage Carbon dioxide transport is interfered with since less reduced hemoglobin is available for this purpose In normal man high oxygen atmospheres cause constriction of coronary and cerebral vessels The rapid relief of oxygen want in chronically hy

poxic individuals by the administration of oxygen has been followed by a train of mental changes which may extend to coma and on occasion, to death The most likely explanation of this sudden deterioration is probably further carbon dioxide retention

Oxygen poisoning has been demonstrated in normal man and in experimental animals The changes are predominantly respiratory in nature Experiments demonstrate that the concentration of oxygen necessary to produce such changes is greater than 60 to 70 per cent When indicated however there should be no hesitancy in employing concentrations up to 100 per cent for hypoxic patients tolerate such concentrations well Frequent removal of the patient from high oxygen atmospheres for feeding reduces the hazard of oxygen poisoning Oxygen poisoning may be a real entity Its danger however should be disregarded in the hypoxic patient for the hazard of oxygen deprivation is infinitely greater

CHAPTER VIII

INDICATIONS

THE INDICATIONS for inhalation therapy are many Its greatest indication however is for the relief of hypoxia Not only may compressed oxygen be given because of its chemical affinity for hemoglobin but gases may be so administered as to aid in oxygen uptake by the blood by altering respiratory dynamics

Inhalation therapy is of value in some non hypoxic states It may be employed for denitrogenization of the body A source of compressed gases may also be employed to carry antibiotic drugs to the pulmonary tree There are a host of conditions in which for one reason or another inhalation therapy seems to be of value

A RELIEF OF HYPOXIA

I ATMOSPHERIC HYPOXIA

In all forms of Atmospheric Hypoxia whether due to breathing air with a normal oxygen percentage at high altitudes or breathing of atmospheres depleted of oxygen as in some form of anesthesia the immediate response is tachypnea If oxygen deprivation is advanced the respiratory center becomes hypoxic and the respiratory threshold becomes elevated Respiration becomes depressed with an ensuing Tidal Hypoxia If the respiratory threshold is sufficiently elevated improved ventilation by artificial means is indicated

When this form of hypoxia is due to high altitudes it is the result of a decrease in the partial pressure of oxygen in the inhaled atmosphere for the percentage of oxygen remains constant Tachypnea causes a blowing off of carbon dioxide with a tendency toward alkalosis Symptoms of oxygen want in some individuals begin at an altitude of no more than 7 000 feet Most individuals will show signs at an altitude of about 10 000–12 000 feet The partial pressure of oxygen at this level is equivalent to the inhala

tion of an oxygen concentration at sea level of about 14 per cent The inhalation of oxygen enriched atmospheres will compensate for the oxygen lack at these levels At an altitude of about 35 000 feet, however even breathing 100 per cent oxygen compensation for the diminished partial pressure of oxygen in the atmosphere begins to fail At this altitude the total barometric pressure is 187 millimeters of mercury Though but 150 millimeters of mercury of oxygen are necessary to oxygenate an individual satisfactorily at sea level, breathing 100 per cent oxygen at 35 000 feet altitude is not quite sufficient because of the partial pressure of water vapor and carbon dioxide In the alveoli water vapor has a pressure of 47 millimeters of mercury and carbon dioxide a pressure of 40 with a total of about 87 millimeters of mercury This total pressure of water vapor and carbon dioxide is not important at sea level but at high altitudes where the total barometric pressure begins to be close to that of the partial pressure of oxygen at sea level it is extremely important since it detracts from the partial pressure of inhaled oxygen Subtracting the 87 millimeters of pressure due to water vapor and carbon dioxide there remains available even breathing 100 per cent oxygen a partial pressure of oxygen of but 100 millimeters of mercury At this altitude and above it is therefore necessary that the oxygen in the inhaled atmosphere be compressed so that its pressure would be greater than the total barometric pressure of the general atmosphere at that level

Atmospheric Hypoxia may be the result of the use of the relatively weak anesthetic agents nitrous oxide or ethylene Unsupplemented these agents may fail to produce anesthesia unless the percentage of oxygen in the inhaled atmosphere is below normal In absorption anesthesia wherein the patient breathes from a closed system Atmospheric Hypoxia may occur if the oxygen delivery into that system is below the patient s metabolic requirements

2A TIDAL HYPOXIA (*Central depression*)

a Disease

Hypoxia due to a decrease in tidal exchange may be the result of cerebral lesions such as tumor abscess or edema It may be due to meningitis or medullary paralysis

b Narcotics and Hypnotics

Drugs such as morphine the barbiturates or anesthetic agents produce Tidal Hypoxia by respiratory depression In the newborn depressed respiration may be due to the effect of depressants administered to the mother

Morphine poisoning Morphine produces a marked diminution in the minute volume exchange because of its depressant effect on the respiratory center The minute volume exchange is decreased due to a marked diminution in rate, rather than in amplitude of respiration The inhalation of high oxygen atmospheres is indicated If the patient s minute volume exchange is not sufficiently great accessory means as artificial ventilation become necessary to supply the patient s needs adequately

Barbiturate poisoning A marked depression in the rate tidal and minute volume exchange of individuals with barbiturate poisoning appears early Inhalation therapy is urgently needed to carry the patient over this period of acute oxygen want Artificial respiration may be indicated here as in the above The period of depression may be prolonged Early in this condition the oxygen want is due to Tidal Hypoxia as the result of respiratory depression This Tidal Hypoxia may be aggravated by the collection of exudate in the tracheobronchial tree which must be removed to ventilate the patient satisfactorily The most common cause of death from barbiturate poisoning if the patient does not succumb early is pneumonia The hypoxia then becomes alveolar in type Efforts have been expended to improve directly the oxygen uptake of tissue by the use of sodium succinate This would seem to be a rational endeavor since the barbiturates not only cause hypoxia by decreasing oxygen uptake through its effect on pulmonary respiration but produce also a histotoxic form of hypoxia by depressing the dehydrogenases The role of sodium succinate in barbiturate poisoning has not yet been completely evaluated Stimulants such as metrazol[R] and picrotoxin have been employed Their action is temporary They in no way however aid in the detoxification and elimination of barbiturates from the body In brief the therapy of barbiturate poisoning should be first the delivery of oxygen to the tracheobronchial tree by inhalation If depression is marked then artificial respiration is necessary All efforts should

be made to guarantee a free airway and the removal of frequent collections of exudates from the trachea by aspiration, when indicated Since the depression may be prolonged the patient s fluid and vitamin intake should be carefully regulated Antibiotics should be administered for the prevention and treatment of pneumonia Sodium succinate, picrotoxin and metrazol[(R)] assume secondary roles

c Anesthetics

Anesthetics produce their effects primarily by action on the higher centers and because of this respiratory depression is not infrequent Tidal Hypoxia is a result of this central effect In addition the anesthetic agents of themselves also depress the dehydrogenases and are thus also guilty of producing Histotoxic Hypoxia Most anesthetic agents are short acting and the histotoxic effect is reversible and not prolonged Here as in other forms of Tidal Hypoxia exposure of the patient to high oxygen atmosphere may not be sufficient to correct the oxygen deprivation The patient s tidal exchange should be augmented by careful intermittent pressure on the breathing bag synchronous with inspiration

d Asphyxia Neonatorum

The etiological factors responsible for depressed or absent respiration in the newborn may be divided into the following

1 Anatomic
2 Obstetric
3 Drug
4 Physiopathologic

Anatomic Among these are malformation of the circulatory and respiratory organs diaphragmatic hernia hypoplasia of the mandible and abnormal mobility of the tongue

Obstetric Prolonged labor compression of the umbilical cord trauma during the passage of the fetus through the birth canal and operative trauma are examples which may be cited

Drug Use of narcotics and hypnotics in mothers to relieve the pains of labor is responsible for an increase in fetal morbidity Narcotics and hypnotics with very few exceptions are respiratory

depressants and are carried through the placenta to affect the respiratory center of the newborn Periods of delayed respiration are the result The true harmful effect of this has not been sufficiently appreciated The use of spinal or epidural anesthesia in obstetrics while of itself not entirely free of harm has very little direct deleterious effect on the baby The marked difference between babies born under spinal and epidural anesthesia as compared with those born under barbiturate medication for example is startling Physicians who have begun their obstetrical experience since the use of barbiturates has been the vogue are pleasantly surprised at the respiratory response of babies born under spinal anesthesia

Physiopathologic Prematurity and intracranial hemorrhage are the two most commonly reported causes to be cited as examples here Dublin and Spiegelman (132) have shown that in spite of steady improvement in neonatal mortality during the past 20 years there has been almost no decrease in the deaths during the first 24 hours after birth It is accepted that oxygen lack plays a major role in over one half of these deaths It is important that those who are responsible for the care of the mother and child during obstetrical procedures know that fetal oxygen want can be recognized before delivery by a drop in the heart rate of the fetus

Administration of oxygen to the mother between contractions will to a large degree correct the bradycardia of the fetus during labor pains (46 263 387) This simple therapy should be instituted especially in situations in which the neonatal mortality is especially high—prematurity multiple births and toxemias of pregnancy (11) The problem of asphyxia neonatorum has been further considered in the section on Ventilatory Resuscitation

2B TIDAL HYPOXIA (*Obstruction*)

The respiratory exchange may be inadequate because of obstruction The obstruction may be pharyngeal laryngeal tracheal or bronchial

a **Pharyngeal obstruction** may be due to tumor foreign body mucus edema abscess or relaxed musculature The treatment is removal of the foreign body or mucus or drainage of abcess if possible If the obstruction is due to relaxed pharyngeal muscles an oral airway should be inserted Oral airways come in all sizes

be made to guarantee a free airway and the removal of frequent collections of exudates from the trachea by aspiration, when indicated Since the depression may be prolonged, the patient s fluid and vitamin intake should be carefully regulated Antibiotics should be administered for the prevention and treatment of pneumonia Sodium succinate picrotoxin and metrazol[8] assume secondary roles

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produce, during inspiration a further increase in the negative intrapleural and intrapulmonary pressure During expiration the intrapleural and intrapulmonary pressures become markedly positive Because of obstruction the respiratory cycle is lengthened, and the respiratory rate is decreased With a prolonged inspiratory effort and an increase in the negative intrapulmonary pressure seepage from capillaries may occur

Because of marked diminution in tidal exchange, carbon dioxide elimination is difficult Inhalation of oxygen itself in these circumstances is of very limited benefit Efforts should be expended to improve tidal exchange One should first attempt to remove the cause of the obstruction Bronchospasm may be relieved by the use of bronchodilating agents Barach (27) has shown that it is possible to improve the tidal exchange by the use of a mixture of gases which are lighter than air—helium and oxygen Helium has a specific gravity one seventh that of nitrogen A mixture of 80 per cent helium and 20 per cent oxygen has a density one third that of room air Moving this mixture requires one half the effort needed for a corresponding atmosphere of room air When helium oxygen mixtures are employed the minimal should be 30 per cent oxygen and 70 per cent helium for if 20 per cent oxygen and 80 per cent helium are employed it has been shown by Motley (278) that in some cases the oxygen saturation of the hemoglobin may decrease He states The breathing may be easier with helium but the oxygen saturation of the arterial blood may not be higher

Few have been as successful in obtaining results with this mixture as has Barach Drinker (128) states In my own observation admittedly slight the advantages gained from helium have not been impressive It is true that helium might pass through a narrow orifice better than does nitrogen A mixture of helium oxygen might pass through an orifice with greater ease than does room air It has been established that helium will pass through single or horizontal obstructions with greater ease than will room air but that in linear obstructions or in a series of narrowed lumina this does not take place This may be the reason why so many have failed in getting satisfactory results with helium oxygen

(Figure 67) They are indicated in the depressed, unconscious individual with pharyngeal obstruction Although primarily developed to be employed in anesthesia, they have a valuable role in medical diseases and should be used more often They should cease to be the valued tool of the anesthetist alone A nasopharyngeal airway is often a great help where an oral airway may not be tolerated or where the patient s mouth cannot be opened to allow one to be inserted These too come in all sizes (Figure 69) These airways oral and nasopharyngeal relieve obstruction by guaranteeing a space between the posterior pharyngeal wall and the tongue (Figures 68 and 70)

Often the vocal cords may be in adduction because of irritation due to foreign body or mucus lying on them, or because of irritants such as anesthetic vapors or industrial gases The treatment here is to remove the irritant source and then by the placement of a tube between the vocal cords to guarantee that they do not approximate and cause respiratory obstruction This tube may be passed through the mouth (Figure 72) or through the nose (Figure 73)

b **Tracheal obstruction** may be due to the presence of tumor foreign body or mucus The trachea may be compressed by external tumor or it may collapse because of inadequate support where the cartilages have been eroded by the pressure of a tumor When the tumor is removed the trachea may collapse Here as in laryngeal obstruction an endotracheal tube may be passed The tube should be of sufficient length to reach below the compressed or obstructed area

In pharyngeal laryngeal or tracheal obstruction where the need is urgent and the placement of the artificial airway cannot be accomplished readily there should no hesitation in performing a tracheotomy

c **Bronchial Obstruction**

Asthma This is a form of Tidal Hypoxia on an obstructive basis The obstruction is due to a narrowing of the air channels from bronchiolar spasm and edematous mucous membrane of the tracheobronchial tree Because of the narrowed lumen increased efforts to improve ventilation are made These increased efforts

must therefore be remembered that not only must means for administering oxygen by inhalation be available with the use of curare and the barbiturates, but that means for artificial respiration should also be at hand

a Emphysema

Here the pathology and affected respiration is due to loss of elasticity in the lung The patient with emphysema cannot make sufficiently active efforts to expel properly gases from his lungs because of the loss of elastic recoil The positive efforts to expel the air from the lungs in a patient with emphysema result in an increase in the intrapleural pressure This intrapleural pressure normally negative, becomes atmospheric or even positive in order to compress the lung to expel the air The air sacs in the patient s lungs become enlarged due either to stretching or to a breakdown in the walls between them The lungs are chronically overdistended In this form of Tidal Hypoxia the minute volume is markedly decreased Emphysema may be a combined form of hypoxia—Tidal Hypoxia because of a decrease in tidal exchange and Alveolar because of a marked decrease in the number of functioning alveoli In emphysema not only is the arterial oxygen saturation apt to be low but carbon dioxide content is elevated because of difficulty in properly eliminating gases within the lung Oxygen by inhalation is only of temporary relief since it does not affect tidal exchange actively These patients are dyspneic and may be tachypneic and, though the minute volume exchange may be normal the tidal exchange remains low and as a result oxygen uptake and carbon dioxide removal are inadequate

Patients with advanced and longstanding emphysema have become adjusted to increased carbon dioxide tension in their alveoli Respiration may have become dependent upon oxygen lack for its regulation The adminstration of high oxygen concentrations to these patients may remove the stimulus of respiration ‘ loss of such stimulation hypoventilation may take resultant increase in retained carbon dioxide Carbon diox accumulate to such a degree that narcosis results For this oxygen should be administered intermittently and with g tion to these patients

Segal (314) summarizes the indications for inhalation therapy in patients with asthma Oxygen may be employed for the relief of oxygen want in these individuals and helium oxygen mixtures should be used for the relief of respiratory obstruction When pulmonary edema exists in these patients positive pressure should be employed with helium oxygen mixtures Such mixtures have, in his experience relieved many patients who failed to respond to other recognized therapeutic measures Positive pressure, if used, should be employed intermittently and for about one hour out of every four as the patient may find it tiring for longer periods

Motley *et al* (282) employed intermittent positive pressure breathing by the Bennett X 2 apparatus (later to be considered) in two cases of asthma with marked relief

2C TIDAL HYPOXIA (*Altered mechanisms*)

Tidal Hypoxia may be the result of altered mechanisms such as occur during convulsions whether due to disease or drug Emphysema shifting mediastinum paradoxical respiration or intercostal paralysis also affect the tidal exchange because of alteration in the dynamics of respiration

Here too the immediate requirement is to supply oxygen to the patient and if the patient s respiratory exchange is not adequate to take up enough oxygen satisfactorily it is necessary that the altered mechanism should be attacked If the respiratory mechanism is altered because of convulsions whether the result of disease or drug the convulsions should be immediately treated They result *in oxygen want because the intercostal muscles do not synchronize* their activity, so that a satisfactory tidal exchange cannot be developed Two drugs are of great aid in overcoming convulsions Intravenous barbiturates carefully administered as well as any of the various forms of curare are of inestimable value in stopping convulsions It must be emphasized that not only may these drugs terminate the convulsions but they are themselves marked respiratory depressants It may then be necessary to ventilate the patient with oxygen to compensate for the depression due to the use of these drugs This procedure is not difficult, for it is easier to ventilate a patient who is in apnea than one in convulsions It

must therefore be remembered that not only must means for administering oxygen by inhalation be available with the use of curare and the barbiturates but that means for artificial respiration should also be at hand

a Emphysema

Here the pathology and affected respiration is due to loss of elasticity in the lung The patient with emphysema cannot make sufficiently active efforts to expel properly gases from his lungs because of the loss of elastic recoil The positive efforts to expel the air from the lungs in a patient with emphysema result in an increase in the intrapleural pressure This intrapleural pressure normally negative becomes atmospheric or even positive in order to compress the lung to expel the air The air sacs in the patient s lungs become enlarged due either to stretching or to a breakdown in the walls between them The lungs are chronically overdistended In this form of Tidal Hypoxia the minute volume is markedly decreased Emphysema may be a combined form of hypoxia—Tidal Hypoxia because of a decrease in tidal exchange and Alveolar because of a marked decrease in the number of functioning alveoli In emphysema not only is the arterial oxygen saturation apt to be low but carbon dioxide content is elevated because of difficulty in properly eliminating gases within the lung Oxygen by inhalation is only of temporary relief since it does not affect tidal exchange actively These patients are dyspneic and may be tachypneic and though the minute volume exchange may be normal the tidal exchange remains low and as a result oxygen uptake and carbon dioxide removal are inadequate

Patients with advanced and longstanding emphysema have become adjusted to increased carbon dioxide tension in their alveoli Respiration may have become dependent upon oxygen lack for its regulation The administration of high oxygen concentrations to these patients may remove the stimulus of respiration (153) With loss of such stimulation hypoventilation may take place with a resultant increase in retained carbon dioxide Carbon dioxide may accumulate to such a degree that narcosis results For this reason oxygen should be administered intermittently and with great caution to these patients

b Shifting Mediastinum

During intrapleural surgery a pneumothorax is created to gain access to the lung With the entrance of air into the pleural space the normal intrapleural negative pressure on the operative side is lost The intrapleural negative pressure on the unoperated side tends to pull the mediastinum towards the good lung Advance of the mediastinum towards the good lung decreases lung capacity and affects the oxygen uptake because of a diminished tidal exchange To guarantee a satisfactory tidal exchange in the non operated lung it becomes necessary to inflate this lung positively This is best accomplished through an endotracheal tube

c Paradoxical Respiration

Because of an inadequate chest support due to operation or trauma the intrapleural negative pressure on the healthy side may pull in the weakened thoracic wall The sucking in of the weakened thoracic walls negates much of the effort necessary to satisfactorily pull into the lungs a normal volume of air Here too it may be necessary to overcome paradoxical respiration by an increased intrapulmonary pressure during inspiration

d Intercostal Paralysis Due to Disease

Anterior poliomyelitis In this disease respiration may be depressed because of intercostal or diaphragmatic paralysis or because of involvement of the respiratory center or cranial nuclei

Respiration becomes shallow, irregular and inefficient In the bulbar forms of poliomyelitis tidal exchange may become further compromised because of collection of exudate in the pharynx Inability to cough allows for the collection of such material in the trachea and bronchi Cranial nerve nuclei involvement may cause respiratory obstruction because of reflex spasm of vocal cords (149)

e Intercostal Paralysis Due to Spinal Anesthesia

This form of intercostal paralysis is due to the action of local anesthetic agents within the subarachnoid space on the motor nerves to the intercostal muscles The extent may be great enough to involve all the intercostal muscles and result in death Intercos

tal paralysis if treated in time is not fatal The alert anesthetist should always recognize intercostal paralysis before any damage has been done Some degree of intercostal paralysis is always present in spinal anesthesia for surgery within the abdomen and can usually be well compensated for by the patient s own respiratory efforts or by administration of oxygen If the paralysis is extensive aid must be given to the patient to maintain a satisfactory minute volume exchange This is best taken care of by the use of the gas

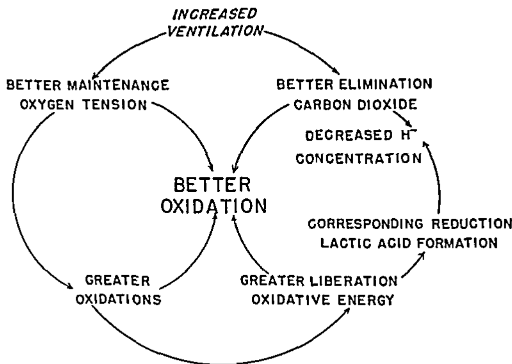


Figure 17 The effect of increased ventilation on better oxidation

machine A tight fitting mask and gas machine are necessary Intermittent pressure on the rebreathing bag which is filled with oxygen is sufficient to ventilate the patient well If there is any problem of maintaining a patent airway or if the patient s respirations do not return to normal in short order artificial respiration should be maintained through an endotracheal tube Respiratory stimulants such as carbon dioxide coramine and the like are contraindicated

In states of Tidal Hypoxia the therapeutic effort is two fold to increase the partial pressure of oxygen in the inhaled atmosphere

and to increase ventilation Inhalation of high oxygen concentrations alone may not be satisfactory An increase in ventilation will not only aid in the availability of oxygen but will encourage the elimination of carbon dioxide (Figure 17)

3 ALVEOLAR HYPOXIA

a Pneumonia

The oxygen want in pneumonia is not only due to a diminution in number of alveoli for proper oxygen uptake but early in this disease a considerable portion of the blood is not well oxygenated because circulation continues to the unaerated portion of the lungs As a result blood which contains a high amount of reduced hemoglobin enters the general circulation Increased rate and decreased amplitude, are signs of respiratory distress There is thus a form of Tidal Hypoxia associated with the Alveolar Hypoxia The degree of oxygen want depends upon the number of involved alveoli and the amount of unoxygenated blood which enters the circulation A not uncommon symptom of pneumonia is delirium This may be due either to toxemia or to oxygen want Accurate measurements may reveal a normal minute volume exchange on occasion but since the tidal exchange is depressed satisfactory oxygen uptake may not be present Associated with this decreased tidal exchange is carbon dioxide accumulation since its elimination is interfered with Inhalation of oxygen is a valuable adjunct in the treatment of pneumonia even with the present day use of antibiotic drugs Much of the tachycardia and respiratory distress can be relieved by oxygen inhalation In spite of extraordinary progress in antibiotic therapy there still exist many forms of pneumonia in which principal dependence must still be placed on general supportive measures such as oxygen therapy (102) Among these are the so called primary atypical pneumonias (virus) In these antibiotic therapy is not so efficacious and indeed oxygen therapy may be the only type of real treatment available

Oxygen therapy may be of great help to older patients suffering with pneumonia or to those with serious underlying disease such as nephritis myocardial infarction or disease of the brain

b Atelectasis

Atelectasis is a term given to an alveolar form of hypoxia wherein there is a marked diminution in the number of functioning alveoli due to unaeration This unaeration is said to be the result of absorption of the air within the alveoli due to bronchiolar obstruction If this condition is recognized early removal of the bronchial obstruction will be followed by immediate aeration of the affected alveoli If the obstruction is not promptly removed infection may set in and the originally non infected atelectatic area may progress to pneumonia The prompt treatment of atelectasis therefore is removal of the exudate which may be the cause of the obstruction Encouragement of the patient to cough is often sufficient to remove the obstruction Otherwise the obstruction should be removed by tracheal or bronchoscopic aspiration Although atelectasis often follows operative procedures it is not at all uncommon in medical diseases Here its occurrence is too often overlooked

Carbon dioxide oxygen mixtures have been recommended in the treatment of atelectasis because of their stimulating effect on respiration and their liquefying effect on secretions There is no question but that carbon dioxide will increase the minute volume exchange and the amplitude of respiration One must not lose sight of the fact that a period of hyperventilation with carbon dioxide and oxygen is followed by a period of hypopnea This hypopnea of itself may encourage further atelectatic formation for carbon dioxide oxygen mixtures are highly absorbable On a rational basis carbon dioxide may be of value if it is not given with more oxygen than there is in room air A method said to be of value is its administration from a cylinder of 100 per cent carbon dioxide mixed with air It must be emphasized and re emphasized at this point that 100 per cent carbon dioxide is irrespirable It is toxic and may be hazardous if it is not given with due care Carbon dioxide is administered slowly from a tube held sufficiently far from the patient so that its concentration is not too great It should be kept there only until the patient hyperventilates Carbon dioxide is further hazardous because of its circulatory effect The adminis

tration of carbon dioxide by this means should not be employed routinely

c Pleural Effusion

Alveolar Hypoxia may be due to the compression of the alveoli by pleural effusions as hydrothorax hematothorax or pyothorax Pneumothorax, by causing a lung to collapse decreases the number of functioning alveoli resulting also in Alveolar Hypoxia

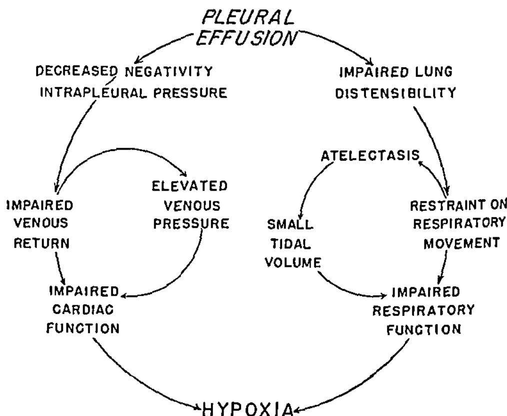


Figure 18 The vicious cycle of pleural effusion producing oxygen deprivation

Altschule and Zamcheck (6) studied the effects of compressed alveoli on respiration and circulation They conclude that pleural effusion impairs respiration and circulation in many ways favoring the occurrence of dyspnea and orthopnea and encouraging oxygen want Atelectasis decreased expansibility of the lungs decreased negativity of intrapleural pressure and shallow respiration are the consequences The circulatory effect is increased peripheral

venous pressure from impaired venous return, the result of changes in intrapleural pressure caused by pleural effusion (Figure 18)

d Pulmonary Edema

The lymphatic system in the lungs cannot cope with large collections of fluid Failure to remove excess fluid is followed by pulmonary edema Welch (388) theorized that pulmonary edema is the result of a disproportion between the working power of the left ventricle and of the right ventricle of such character that the resistance being the same the left heart is unable to expel in a unit of time the same quantity of blood as the right heart

The factors involved in the pathogenesis of pulmonary edema are (38)

1 Left ventricular failure
2 Increased permeability of the pulmonary capillaries
3 a A persisting pathologically elevated negative pressure within the chest or
  b An abrupt termination of respiratory effort and a consequent loss of the backward pressure on the pulmonary capillaries

Pulmonary edema may be produced by oxygen lack and sustained increase in pulmonary capillary pressure (128) Neither cause ever works alone since sooner or later the other factor begins to operate Diminished oxygen results in increased capillary permeability since the endothelium of the lungs is significantly assailable by oxygen want Simple pulmonary edema and pulmonary exudation depend more upon alterations in the permeability of the lung capillaries than upon complicated pressure circulatory relations Heightened intrapleural negative pressure alone may produce pulmonary edema but in the absence of oxygen want this is unlikely except in the presence of already leaking capillaries

Obstructive lesions in the tracheobronchial tree may increase intrapulmonary negative pressure Inability to draw in air during forced inspiration causes this rise Pulmonary edema is not only encouraged by an increased intrapleural negative pressure by direct action on the capillaries but the heightened negative pressure facilitates entrance of blood into the right heart and causes stasis in the pulmonary bed

Alterations in intracapillary pressure with pulmonary edema may not only be produced by left ventricular failure but also by peripheral circulatory collapse

Industrial gases such as phosgene and chlorine, may so injure the pulmonary endothelium as to cause an increased transudation of fluid with a resultant edema

The treatment of pulmonary edema depends upon its cause Since oxygen lack produces an increased flow of lymph efforts to relieve hypoxia by oxygen inhalation should be started immediately For if no great damage has already been caused, the flow of lymph into alveoli and the bronchi will be prevented With delay and increasing collection of exudates, simple exposure of the patient to heightened atmospheres of oxygen will not relieve the condition Drinker (128) believes that if conditions of abnormal leakage continue until excess fluid has made a considerable entrance into alveoli and bronchioles one cannot expect prompt and complete relief from breathing oxygen therefore the sooner the oxygen is given the greater the possibility of checking leakage from lung capillaries Exposure of a patient to oxygen alone however will not relieve the condition if there is any interference with proper ventilation of portions of the lung The oxygen must be forced into alveoli, alveolar ducts and bronchioles through which it must first pass to improve the condition of capillaries

Haven Emerson (142) relieved pulmonary edema produced by adrenalin by artificial respiration accompanied by an increase in the intrapulmonary pressure during the inspiratory phase of respiration Auer and Gates (16) believed that the relief of pulmonary *edema by increased intrapulmonary pressure was the result of the* direct effect upon the capillaries rather than through secondary action on the heart Loeb (257) and Plesch (300) also determined that replacement of the intrapulmonary negative pressure during inspiration by atmospheric or positive pressure had a beneficial effect on relieving the increased exudation during pulmonary edema

Motley *et al* (282) have three possible explanations of the way in which positive pressure relieves pulmonary edema 1) The very presence of pressure 2) the dry compressed gases and hyperventilation removes small but significant amounts of moisture 3) in

creased lymphatic flow. Drinker (128) showed that intermittent positive pressure breathing causes a marked increase in lymphatic flow in the dog. Motley *et al.* (282) noted that intermittent positive pressure breathing may be expected to relieve pulmonary edema when 1) the onset is sudden, 2) the arterial blood pressure is maintained, and 3) no pneumonia is present.

More recently, Barach, Martin and Eckman (38), as well as Hardy and Barach (198) treated by increased pressure a series of patients with pulmonary edema due to the effects of chlorine and nitric acid with good results, as did Carlisle (89).

Barach (27) showed the beneficial effect of direct physical pressure by oxygen in pulmonary edema due to irritant gases. Fifty per cent of the applied pulmonary pressure bears on the capillary wall and by direct action prevents the seepage of fluid through the wall. The rest of the applied pressure is taken up by the elasticity of the lung. In pulmonary edema, oxygen under increased pressure works in two ways. There is the physical effect of the pressure and the metabolic effect. The increased oxygen tension is tonic to the damaged capillary wall and interrupts the hypoxial cycles in the body.

In patients with asthma or lesions of the respiratory passageway which produce obstruction, the pressure is best administered, Barach (27) believes, during both inspiration and expiration. No harmful effects have been noted as far as dyspnea is concerned by breathing out against a positive pressure under these circumstances. In fact, positive pressure respiration tends to maintain a more patent lumen during expiration in the intrathoracic bronchi. Barach (27) states that the treatment of pulmonary edema in shock should be in a manner different from the treatment of straight pulmonary pathology with edema and that, in peripheral circulatory failure there is already a deficient return of blood to the right heart and the presence within the lung of an increased intrapulmonary pressure may further retard the flow of blood into the right auricle. Because of this caution must be exerted in the treatment of pulmonary edema in the presence of shock. Barach says that a very few cases of pulmonary edema in shock have been treated, but there is sufficient physiologic evidence at hand to warn against the use of increased pressure.

e Anthracosilicosis

The prolonged inhalation of silica dust will produce some degree of pulmonary fibrosis The disease is characterized by dyspnea frequent superimposed respiratory infection and occasionally failure of the pulmonary circulation in terminal states Motley *et al* (280) showed that in anthracosilicosis there was a decrease in maximal breathing capacity In those patients in whom emphysema played a prominent role ECG studies have shown strain of the right side of the heart There was a significant correlation between the right heart strain pattern and the degree of emphysema

At rest, these patients had an average arterial blood oxygen saturation of 90–93 per cent With exercise however the degree of saturation fell The higher the degree of emphysema the greater was the decrease in arterial oxygen values The arterial pCO_2 increased progressively as the emphysema increased

These authors found the most effective treatment to be simultaneous use of intermittent positive pressure breathing and nebulization of vasoconstrictors Such therapy encouraged bronchial drainage relieved bronchospasm and improved ventilation with an increased oxygen saturation of the arterial blood

Up to this point Atmospheric Tidal and Alveolar hypoxia have been considered They represent what was termed by Barcroft anoxic anoxia These forms of oxygen want have a common characteristic They are all associated with arterial hypoxemia that is the arterial oxygen content is less than normal Because of this circumstance inhalation therapy is of value Since it is possible further to load the red cells and plasma going through the lungs with oxygen much of the arterial hypoxemia can be relieved (Figure 12)

4 HEMOGLOBIC HYPOXIA

This form of hypoxia is the result of a decrease in the amount of hemoglobin available to carry oxygen The hemoglobin may be diminished because of lack of carriers such as red cells, or it may have entered into chemical combination with a drug such as carbon monoxide

In Hemoglobic Hypoxia whether due to loss of red blood cells

or to partial fixation of hemoglobin by carbon monoxide, what ever hemoglobin is available to carry oxygen is normally saturated The percentage saturation may be normal, but the oxygen content is decreased The administration of oxygen by inhalation will but very slightly elevate the degree of oxygen saturation of the red blood cells It will, however, increase the amount of oxygen physically dissolved in plasma tenfold The endeavor, then, is worthwhile

a Hemorrhage

The treatment of acute blood loss is of course blood transfusion An important adjunct is inhalation therapy for whatever hemoglobin is present can be completely saturated and the plasma content can be markedly increased

In regard to chronic anemia Barach (23) states Oxygen therapy is contraindicated in chronic anemia such as pernicious anemia as a stimulus for the production of red cells is thus withdrawn and a lowered red blood count will follow In acute severe anemia which may occur from blood loss oxygen therapy is indicated until transfusions make up for the hemoglobin depletion

b Carbon Monoxide Poisoning

Carbon monoxide has a twofold effect in producing oxygen want in the body As stated above it interferes with the oxygen carrying ability of hemoglobin by forming carboxyhemoglobin This affinity of carbon monoxide for hemoglobin is many times greater than oxygen with hemoglobin The other and important effect of carbon monoxide in producing hypoxia is a histotoxic effect on the tissue cell directly Thus the hypoxia produced by carbon monoxide is both Hemoglobic and Histotoxic

Henderson and Haggard (189 208) advocated the use of carbon dioxide in the treatment of carbon monoxide poisoning for two possible effects Carbon dioxide by its respiratory stimulating effect i e increasing respiratory amplitude and minute volume exchange may more readily bring about elimination of carbon monoxide Carbon dioxide causes a lowered pH of the blood This lowered pH of the blood decreases the affinity of hemoglobin for carbon monoxide and accelerates its removal from the blood (123

190 364) Sayers and Yant (332) however concluded that carbon dioxide oxygen mixtures are not of any greater value in the treatment of carbon monoxide poisoning than is oxygen alone Rossiter (316) points out that the patients to whom Henderson and Haggard administered carbon dioxide for the treatment of carbon monoxide poisoning had a blood saturation of carbon monoxide of between 40 and 50 per cent When the saturation is greater than 50 per cent the heart is weakened by the associated hypoxia and the hazard of carbon dioxide causing circulatory failure in these individuals is great Drinker and Shaughnessy (130) though admitting that in carbon monoxide poisoning the heart becomes dilated and both cardiac output and blood pressure fall, think that carbon dioxide may still be of value They feel that since *early* in carbon monoxide poisoning there is an associated hyperpnea with a resultant loss of carbon dioxide, this should be replaced to maintain a normal chemical equilibrium Whereas others have recommended a mixture of 95 per cent oxygen and 5 per cent carbon dioxide Drinker and Shaughnessy recommend a mixture of 93 per cent oxygen and 7 per cent carbon dioxide since 7 per cent carbon dioxide is more likely to produce a satisfactory augmentation of respiration

Oxygen inhalation causes a fourfold and carbon dioxide a five fold increase in the elimination of carbon monoxide as compared with inhalation of air (126) Judged from the time necessary to recover from a given exposure to carbon monoxide with a given blood saturation however there seems to be no advantage in the use of carbon dioxide

Nicloux Nerson Stahl and Weill (286) as well as Walton *et al* (385) found that there was very slight if any difference in aiding elimination of carbon monoxide by the use of either oxygen or carbon dioxide

Schwerma *et al* (342) state The only effects of the administration of exogenous carbon dioxide are the slightly more rapid excretion of carbon monoxide and in some cases a more rapid restoration of respiratory movements The significance of these effects has been exaggerated while the much greater significance of adequate cardiac function has in large part been overlooked Since carbon dioxide plays no demonstrable part in fortifying cardiac

function and its addition to oxygen confers no further value in resuscitation, the inevitable conclusion is that it is an unnecessary therapeutic adjunct Schwerma *et al* (311) point out that in regard to survival and the incidence and severity of neurologic sequelae no difference was found between the use of 100 per cent oxygen and 7 per cent carbon dioxide in oxygen

Inasmuch as carbon dioxide does not seem to speed recovery from carbon monoxide poisoning it would seem to be contraindicated because of its circulatory effects The anesthetist frequently sees hypoxic, depressed patients and has learned not to rely on or use carbon dioxide for its stimulating effect He is constantly aware of the hazard of carbon dioxide and endeavors constantly to prevent his patient from being exposed to it

Other drugs which may combine with hemoglobin to produce Hemoglobic Hypoxia are nitrobenzene nitrophenols acetanilid and potassium chloride

In Hemoglobic Hypoxia as already stated whatever hemoglobin is available to carry oxygen is 95 per cent saturated The inhalation of high oxygen concentrations however, will increase the oxygen content of the plasma in arterial blood by two volumes per cent This may not seem much in normal individuals whose oxygen content of arterial blood is approximately 20 cubic centimeters per 100 cubic centimeters Under these circumstances the increase would amount to no more than 10 per cent In individuals poisoned by carbon monoxide however the total arterial oxygen content may be no more than 8 to 10 cubic centimeters per 100 cubic centimeters Here the increase due to saturating the plasma with oxygen would be about *20 to 25 per cent This in*crease in oxygen in the arterial blood may be sufficient to be life saving (Figure 13)

5 STAGNANT HYPOXIA

In states of circulatory inefficiency there is stagnation of blood in the lungs and peripheral structures

a Circulatory inefficiency, cardiac in origin may be due to left sided or combined right and left sided congestive failure myocardial infarction or cor pulmonale Circulatory inefficiency based on a failing right heart results in an inadequacy of the right heart

in advancing blood, with its consequent stagnation in the peripheral structures Left hearted failure, with a resultant inefficiency in blood delivery is followed by an inadequate uptake of blood from the lungs with a consequent congestion in these latter structures In either event there is stagnation of blood Because of increased circulating time through the capillaries more oxygen is taken up per unit of blood Whatever blood is advanced into the circulation by the left heart is fully laden with oxygen Because of the increased duration of its stay within the capillaries and because more oxygen is taken up from it the venous blood is very low in oxygen content, thus the arteriovenous oxygen difference is great This is Stagnant Hypoxia In cases of advanced left hearted failure there may be edema in the alveoli and thus we have a combined form of oxygen want—Stagnant Hypoxia because of circulatory failure and Alveolar Hypoxia which is secondary to it There is an associated interference with respiratory exchange because of the edema To Stagnant and Alveolar Hypoxia we then have the added Tidal Hypoxia This effort to increase respiration by minute volume exchange produces dyspnea Dyspnea is an effort to maintain normal arterial oxygen saturation It is the result of the combined Alveolar and Tidal forms of hypoxia

Richards (311) recommends oxygen in the treatment of cardiac failure and as indications for its use he cites dyspnea restlessness cyanosis cardiac pain and cough Carbon dioxide he believes is contraindicated in the therapy of this condition It has been his experience that in acute left ventricular failure with pulmonary congestion and edema the use of expiratory positive pressure for a few hours has resulted in a decrease in pulmonary rales and corresponding clinical improvement

Damming back of the venous return to the chest produced by positive pressure breathing results in a decrease in cardiac output in normal subjects, but an increase in cardiac output in some cases of congestive heart failure (282) Positive pressure apparently prevents an excessive venous return and acts in a manner similar to the employment of tourniquets on the limbs or of phlebotomy

Poulton (303) had shown that patients suffering from rheumatic carditis showed marked improvement when treated by oxygen inhalation Temperature and pulse were lowered Cardiac murmurs were altered and the heart size was diminished with im

provement in electrocardiographic findings Iaran *et al* (370) have treated many such patients with dramatically good results They too found improvement in regard to body weight and appetite There was a rapid and significant drop in temperature with a decreased respiratory rate, a dramatic and consistent drop in pulse rate and stabilization of the cardiac rate Stabilization of the heart sounds occurred and there was a subsistence of cardiac symptoms of angina fatigability palpitation and dyspnea on exertion ECG studies showed disappearance of the signs of conduction disturbances There was a consistent disappearance of the signs of oxygen want and changes in duration of electrical events in the cardiac cycle

These authors suggest a physiologic process which may play an important role in the improvement observed in these patients Cardiac damage from acute carditis is due to a failure to attain effective cardiac rest during the course of the disease Inhalation therapy will result in better cardiac rest than that which may be achieved under the best physical and emotional environment

In rheumatic carditis the increased heart rate may be a compensatory expression of myocardial hypoxia Overactivity of cardiac action in acute carditis disturbs the normal time relationships of systole to diastole The accelerated pulse rate per se further diminishes diastolic coronary filling and thus increases the already existing myocardial hypoxia Oxygen therapy restores the normal relationships in the duration of the systole to that of the diastole In a study by these authors (370) it was shown that there was an increase in the duration of diastole as the result of inhalation of oxygen With an average reduction in cardiac rate from 106 to 86 there was an increased duration of diastole of 2 3 seconds per minute This is an improvement of two minutes and 19 seconds per hour or 56 minutes a day They state that it is reasonable to assume that an increase in the period of cardiac relaxation might tend to bring about a more normal chemical economy of the heart muscle by restoring the normal oxygen balance

b Coronary Occlusion

Because of thrombosis or spasm of a coronary blood vessel ischemia of heart muscle develops The common symptom of this condition is pain It is pretty generally accepted that the pain is

due to myocardial ischemia It has been shown that ischemia of the heart muscle produced by inhalation of low oxygen atmospheres produces pain Another indication that the pain in coronary occlusion is due to ischemia is the fact that inhalation of oxygen often relieves this pain The hypoxia incident to coronary occlusion is another example of the vicious cycle established by oxygen want It is further support of Drinker's statement that anoxia begets anoxia (128) As may be seen in Figure 19 coronary oc

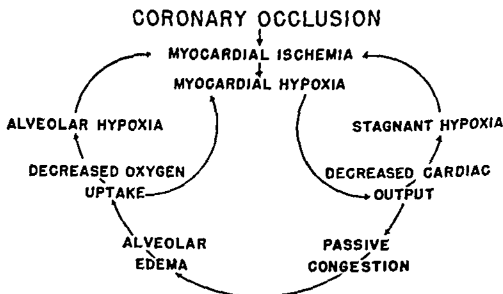


Figure 19 The vicious cycle of oxygen deprivation and coronary occlusion

clusion results in myocardial ischemia with the production of myocardial hypoxia Myocardial hypoxia results in decreased cardiac output Decreased cardiac output produces Stagnant Hypoxia which in turn results in myocardial hypoxia and a small vicious cycle is here set up Decreased cardiac output is followed by passive congestion which results in alveolar edema Alveolar edema results in a decreased oxygen uptake by the blood This decreased oxygen uptake is a form of Alveolar Hypoxia and of itself will produce myocardial hypoxia So again is produced the main vicious cycle—myocardial hypoxia decreased cardiac output passive congestion alveolar edema decreased oxygen uptake and again myocardial hypoxia

The immediate myocardial ischemia with stagnation of the

blood produces a Stagnant Hypoxia As other structures become involved, particularly the lungs, hypoxia of the alveolar type is superimposed upon Stagnant Hypoxia Though the inhalation of oxygen in Stagnant Hypoxia is not entirely satisfactory at best one can hope for an increase of about 2 volumes per cent Though this is not to be disparaged, the great aid from inhalation therapy comes when Alveolar Hypoxia has become part of the picture, for here the addition of oxygen will result in a definite loading of the arterial blood with oxygen One should immediately institute oxygen administration in these cases and not wait until added oxygen need is evidenced

Oxygen therapy has an important role in the treatment of acute coronary occlusion Increased oxygen pressure in the arterial blood during therapy tends to alleviate the effects of coronary constriction (308 309 310)

Levy (248) gives the following as clinical criteria which indicate the need for oxygen therapy in this condition cyanosis shock severe and persistent cardiac pain dyspnea acute pulmonary edema congestive failure certain cardiac arrhythmias rising heart rate sharp fall in blood pressure marked leukocytosis high fever and Cheyne Stokes respiration In regard to the effect of oxygen in the treatment of this condition he says that the following specific inferences are justified

1 Oxygen therapy brings about subjective improvement Pain is lessened or abolished the heart rate falls and respiration is slower and less labored The patient is no longer restless It is possible to curtail materially or stop entirely the use of opiates and sedative

2 The state of shock gradually disappears

3 Cyanosis is diminished or abolished

4 The onset of congestive failure may be prevented and oxygen aids in controlling it after its occurrence

5 The temperature when elevated tends to fall

6 Cheyne Stokes breathing if present is gradually followed by regular respiration

7 Of great significance is the fact that interruption of oxygen therapy before adequate readjustment of circulatory conditions has taken place results in recurrence of the symptoms and signs just described Resumption again proves helpful

Boland (69) believes that the administration of high oxygen concentrations relieves the intractable pain of coronary occlusion. It has been felt that such therapy frequently controls pain even in the absence of pulmonary edema and subnormal oxygen saturation of the arterial blood. There is, however, an important contrary view as expressed by Russek, Regan and Naegele (321). They state that the administration of 100 per cent oxygen for angina *pectoris and for pain accompanying acute myocardial infarction* without arterial hypoxemia is of very little if any benefit. It is their contention, on the contrary, that in cases of myocardial infarction the disturbance to the patient which may be provoked by such therapeutic endeavors may be detrimental.

These authors set out to determine whether or not high concentrations of oxygen actually relieve clinical states of coronary insufficiency which are unattended by generalized arterial hypoxemia. They employed the Master two step test * in experimentally inducing coronary insufficiency. They had previously pointed out that certain patients with angina pectoris showed transient ECG changes in response to this test. They used this test as a control of the value of oxygen prophylactically and therapeutically. They employed for their study five patients in whom the two step procedure evoked a constant positive ECG response. They did this with the patient breathing air and then breathing oxygen and report that in each of the five cases 100 per cent oxygen was without effect in preventing the RS T segment and T wave changes observed in the control records.

Similarly they found that the continuous administration of 100 per cent oxygen during the post exercise period failed to hasten the disappearance of the ECG changes. They did note, indeed, that when 100 per cent oxygen had been administered the changes were either more pronounced or longer in evidence in four of *the five patients and that in every instance such therapy failed to* prevent the onset of anginal pain or to influence its duration.

They do admit, however, that oxygen administration is a valuable therapeutic measure in patients with acute myocardial infarction in whom there is some pulmonary congestion resulting in

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* See page 118

hypoxemia and under such circumstances there is a striking relief of pain and restlessness and a diminution of cyanosis They seriously question whether or not hyperoxygenated blood is capable of influencing local myocardial hypoxia

In explanation of the contrary effects on the ECG reading they rationalize that a temporary occlusion of the coronary vessels is followed by a powerful reactive hyperemia that a mechanism exists which adapts the coronary flow to the needs of the moment and this need is associated with the production locally of a vasodilating substance and that high oxygen tension in the blood will prevent the liberation of this vasodilator material They state It is possible that hyperoxygenated blood may prevent or reverse it (the local vasodilating response) so that local anoxia of equal or greater degree is evoked by standard stimulus They state further The false hope that the size of the resultant infarct in such cases can be influenced by oxygen therapy should therefore be abandoned Similarly no benefits should be anticipated from the administration of 100 per cent oxygen for the relief of recurrent or intractable pain in these patients

This work is indeed important and should be either supported or refuted by additional work In reviewing their work one notes that before these patients received oxygen for the test they were breathing air with a B L B mask This breathing of air with a B L B mask will unquestionably result in alteration in the intrapulmonary pressure because of the necessity to inhale and exhale the respired mixture through sponge rubber discs Further such therapy is unquestionably associated with some carbon dioxide accumulation which in itself may have an effect on the cardiac conduction mechanism

They state that 100 per cent oxygen was delivered into a B L B mask Unless valves with special flow characteristics are employed it is almost impossible to deliver a mixture of oxygen into the bag which will result in a 100 per cent oxygen atmosphere without some carbon dioxide accumulation Without repeating the work one can question the plausibility of the role of carbon dioxide in preventing relief from the oxygen inhalation

As noted previously this work is of sufficient importance that one should withhold conclusions until further evidence is at hand

Because of pain and apprehension and also as a result of some associated oxygen want, the patient suffering from acute coronary occlusion may hyperventilate thus blowing off some carbon dioxide. Alkalosis may occur. Alkalosis has a tendency to cause capillary constriction of the coronary circulation, thus enhancing myocardial ischemia.

Yandell Henderson (204) recommended the use of a carbon dioxide oxygen mixture in the treatment of angina noting that there was less substernal oppression and pain associated with its use. Here too one should warn against the use of carbon dioxide in these conditions because of its circulatory effect.

The anoxemia test for coronary insufficiency. Resnik (308) pointed out in 1925 that under conditions of oxygen want changes in cardiac conduction occur and a damaged heart when subjected to anoxemia may early exhibit functional disturbances which may appear only in the presence of a more profound anoxemia in the normal heart. Danielopolu (111) advanced the theory that angina pectoris is due to a disproportion between the flow of blood in the coronary vessels on the one hand and the work of the heart on the other. He pointed out that even if a heart has normal arteries and the demands are great enough coronary artery insufficiency may become so marked as to lead to angina and that when these arteries are diseased lesser demands will bring on the anginal syndrome. He did not offer satisfactory evidence that there may be coronary insufficiency in the presence of normal coronary arteries. This evidence appeared much later in the work of Rothschild and Kissin (318) and Levy *et al.* (249).

In 1928 Keefer and Resnik (229) expressed the belief that angina pectoris is always due to myocardial hypoxia. They summarize the work on the conduction mechanism of the heart in relation to hypoxia as follows: It has been shown that attacks of anginal pain induced by anoxemia are identical with spontaneous attacks, that anoxemia is at least in part responsible for the pain of angina pectoris and that associated with either spontaneous or induced attacks there are characteristic changes in the electrocardiogram.

Levy, Bruenn and Russell (249) presented a clinical test for coronary insufficiency by exposing the patient to low oxygen concentrations. They employed the dilution method of producing a

low oxygen atmosphere They as did Levy exposed the patients to a 10 per cent oxygen mixture They used patients students and nurses in the four decades 21 to 30 31 to 40 41 to 50 and 51 to 60 years of age The older subjects showed an average response which is practically identical with the average for the younger They summarized the electrocardiographic observations on normal subjects who showed a normal response to hypoxemia There is an early and prompt depression of all T waves especially T_3 and with this a deviation of the RS T segment from the isoelectric line This is in agreement with the criteria of Levy *et al* for the normal response to hypoxemia The following are Levy s criteria of an abnormal response (247)

1 The arithmetic sum of the RS T deviations in all four leads totals three millimeters or more

2 Partial or complete reversal in the direction of T in Lead 1 if accompanied by RS T deviation of one millimeter or more in this lead

3 Complete reversal in the direction of T in Lead IVF regardless of RS T deviation

4 Partial reversal in the direction of T in Lead IVF if accompanied by RS T deviation of one millimeter or more in this lead

Some subjects showed what was according to Levy an abnormal response to induced hypoxia but the history absence of symptoms and physical examinations failed to reveal any evidence of cardiovascular disease There was no history of chest pain congestive failure or hypertension In all cases the control electrocardiogram was normal in all four leads Twenty four of 125 normal persons (19 2 per cent) showed an abnormal response according to the criteria of Levy Twenty two of the 24 showed complete reversal of T in Lead IVF etc Because of this work they state that it therefore appears that reversal of T in Lead IVF (Criterion 3) in response to induced anoxemia cannot be accepted as indicative of coronary insufficiency

Levy (246) reported two instances of convulsions during the test He states that it appears evident from even this limited number of cases that constant observation during the test for evidence of oxygen deprivation may not prevent the development of a sufficient degree of cerebral damage to lead to convulsion Cerebral hypoxia may produce perivascular hemorrhage and edema of the

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and is probably less likely to cause the untoward results that have been associated with the inhalation of low concentrations of oxygen

c Shock

It has been shown that disturbed circulatory states known as shock regardless of cause have a common characteristic—increased capillary permeability with transudation of fluids Anything which injures the capillary wall and encourages capillary permeability may be an etiological factor in shock The single and most important factor for the production of increased capillary permeability of the capillary wall is oxygen lack Anything which produces oxygen lack will produce shock With the circulatory deficiency in surgical shock, tachycardia decreased cardiac output, decreased blood volume and increased circulatory time Stagnant Hypoxia develops

As previously stated in Stagnant Hypoxia there is no arterial hypoxemia (Figure 14) The arterial oxygen content and its percentage saturation are normal Because the circulation is very slow there is a good deal of oxygen taken up per unit of blood There is an increased arteriovenous difference Here as in any other form of Stagnant Hypoxia oxygen therapy can increase the amount of oxygen which is physically dissolved The increased head of oxygen pressure is important

If this circulatory deficiency is due to hemorrhage with resultant hemodilution the oxygen capacity of arterial blood is decreased Thus an increase of two volumes per cent of oxygen physically dissolved in plasma will be a relatively large increase in the oxygen capacity of that blood If the circulatory state is due to trauma or burns wherein there is hemoconcentration the arterial oxygen capacity is increased because of hemoconcentration and loading the plasma with additional oxygen will not bear the same important ratio as it does in hemorrhage This however should not be construed to mean that oxygen should not be used in states of shock due to trauma or burns

Ohlsson *et al* (289) feel that a favorable effect of oxygen administration not previously mentioned in the literature is that

brain which may be irreversible The authors of this article encountered untoward symptoms in 17 instances in a total of 189 tests In all but two of these instances they were impelled to interrupt the test Five had symptoms of such severity as to furnish cause for alarm They speak of the hazards of the hypoxia and they state that a 10 per cent mixture is equivalent to an altitude of 19 200 feet Both cardiovascular and cerebral disturbances have occurred in the course of induced anoxemia tests Levy *et al* (247) reported three instances of acute pulmonary edema One patient was in shock after 10 minutes of hypoxemia The authors found that in induced oxygen deprivation studies in certain instances there was a sudden and profound reduction in the blood pressure which although transient might furnish the precipitating factor leading to infarction Again in the author s experiments in five instances much twitching occurred in the course of the test and in two of these progressive generalized convulsions occurred before the hypoxia could be terminated by oxygen inhalation

Hartman (203) has stated that one may encounter later neural lesions In conclusion the authors make it quite clear that they do not believe that this exposure to oxygen want is a diagnostic test and that induced hypoxia cannot be considered a routine laboratory procedure because of its danger

Master (268) proposed a two step exercise tolerance test in attempting to evaluate cardiovascular function The patient, depending upon his size and weight ascends and descends two nine inch steps a variable number of times With the P R interval as a control level depression of the RS T segment in any lead of over 0 5 mm below the isoelectric level is considered positive for coronary heart disease Depression of the T wave or its inversion except in Lead 3 is also an abnormal response

Baum *et al* (50) found that depression of the RS T segment did not occur in normal individuals It should be emphasized that this Master two step test should be employed only when the resting electrocardiogram is normal If the resting electrocardiogram is abnormal then an exercise test is obviously unnecessary This test is probably as indicative of coronary heart disease as is the electrocardiographic response to the inhalation of low oxygen mixtures

reached the pulse rate climbed rapidly to the same level as in the first group, but slowed after the oxygen was administered and remained at the lower level during the course of the treatment In the group given prophylactic oxygen therapy with or shortly after the initiation of fever the pulse rate became elevated but never reached the high level of the two previous groups and it

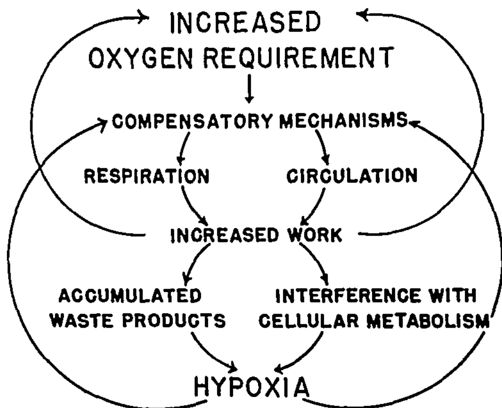


Figure 20 The vicious cycle of increased oxygen requirements and oxygen deprivation

persisted at this relatively low level during the hyperthermia Restlessness mental confusion and excitement were less frequent and less marked in the patients receiving oxygen therapy In some of the patients who received no oxygen therapy treatment had to be discontinued because of either extreme tachycardia or uncontrollable excitement These same individuals tolerated the treatment satisfactorily when oxygen therapy was employed Cullen *et al* hold that the above is evidence of oxygen want during a period of hyperpyrexia

such administration leads to a transient (but important) increase in the volume of circulating blood corresponding to an ordinary blood transfusion

6 HISTOTOXIC HYPOXIA

The low oxygen utilization of tissue in this form of hypoxia is due to metabolic dysfunction in the cell The arterial oxygen content and percentage saturation are normal Because oxygen uptake is so small the venous oxygen is elevated above normal and thus the arteriovenous difference is narrowed

Oxygen inhalation is of very limited usefulness in Histotoxic Hypoxia because of this The remedy lies in the removal of the etiological factors Efforts to employ agents as cytochrome-c and sodium succinate in attempting to increase oxygen uptake are not the final answer but are probably steps in the right direction

7 DEMAND HYPOXIA

Because of increased demand for oxygen due to fever pain excitement or other factors there is an augmentation of oxygen uptake from the inhaled atmosphere The minute volume exchange is increased circulatory time is decreased and the pulse rate becomes elevated in efforts to satisfy the tissue requirements for oxygen

With full compensation hypoxia is but potential If oxygen requirements are not met hypoxia results Vicious cycles become established (Figure 20) The very compensatory efforts of themselves mean more work This means an additional oxygen need Administration of oxygen may be sufficient to relieve the compensatory mechanism of a considerable burden

This has been well shown by Cullen *et al* (110) in hyperpyrexia Studies were made on patients with induced fever One group had no oxygen another had oxygen administered after the temperature became elevated and a third was administered oxygen throughout the entire period The effects of oxygen inhalation on the pulse rate were observed (Figure 21) In the group which received no oxygen therapy the pulse rate climbed rapidly to a high level and continued to increase as the treatment progressed In the group given oxygen therapy after the desired level of fever had been

of fever (7 per cent for each one degree rise Fahrenheit) or because of hyperthyroidism patients often respond dramatically to oxygen inhalation by a slowing of the pulse and respiratory rates and an improved sense of comfort Very often excitement and delirium, when present disappear

The symptoms of thyrotoxicosis are often markedly relieved by inhalation therapy This form of treatment is commonly employed

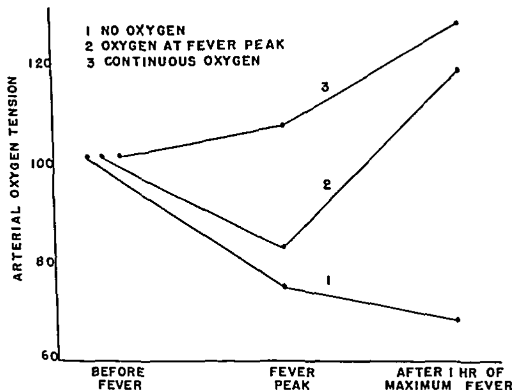


Figure 22 The effect of inhalation therapy on arterial oxygen tension of patients undergoing fever therapy (From Cullen S C Weir E F and Cook E The Rationale of Fever Therapy *Anesthesiology* 3 2 123–130 March 1942)

postoperatively The preoperative use of oxygen in patients with hyperthyroidism has not received sufficient clinical trial Patients with increased oxygen requirements can be better prepared for surgery if administered oxygen by nasal catheter for several days before coming to surgery

B DENITROGENIZATION

According to the law of gases the diffusion of any gas through a semi permeable membrane is proportional to the difference be

The effect of inhalation of oxygen on the oxygen tension in arterial blood is shown in Figure 22 In the group receiving no oxygen therapy during treatment the arterial tension fell as much as 25 per cent with the development of the desired level of fever It continued to fall as the treatment progressed The patients receiving oxygen therapy after the desired level of fever had been reached

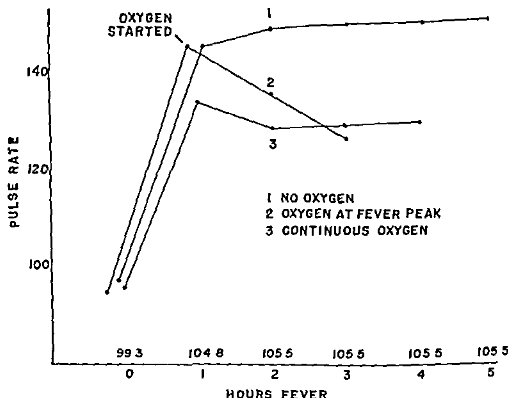


Figure 21 The effect of oxygen inhalation on the pulse rate of patients undergoing fever therapy (From Cullen S C Weir E F and Cook E The Rationale of Oxygen Therapy During Fever Therapy *Anesthesiology* 3 2 123–130 March 1942)

had an arterial tension fall of 18 per cent and with the administration of oxygen a rise to a point 19 per cent above the original level In those who received oxygen during the whole treatment there was no drop in tension but rather a continuous rise

The findings of Looney and Borkovic (259) do not substantiate the above work Though their work is not to be brushed aside lightly clinical experience supports the findings of Cullen *et al* In clinical practice when oxygen consumption is elevated because

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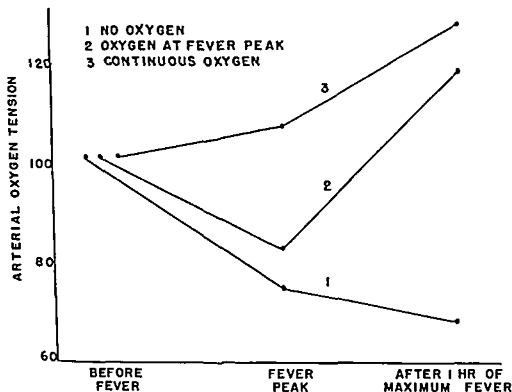


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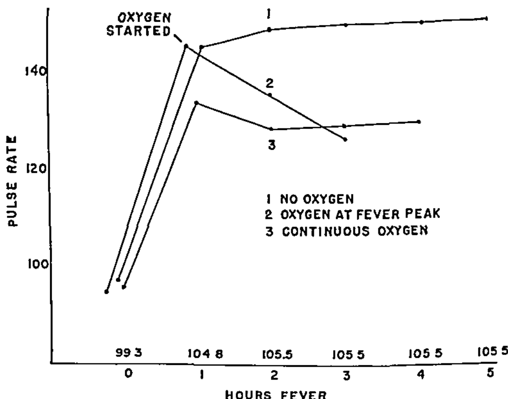


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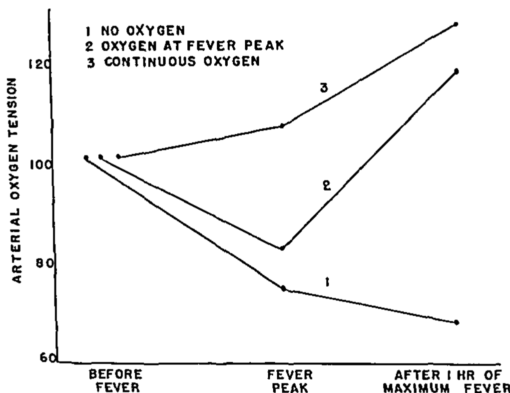


Figure 24 The effect of inhalation therapy on arterial oxygen tension of patients undergoing fever therapy (From Cullen S C Weir E F and Cook E The Rationale of Fever Therapy *Anesthesiology* 3 2 123–130 March 1942)

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B DENITROGENIZATION

According to the law of gases the diffusion of any gas through a semi permeable membrane is proportional to the difference be

tween its partial pressure upon the two sides Nitrogen a normal constituent of blood and tissue exerts a partial pressure of approximately 570 millimeters of mercury in arterial blood Fine *et al* (157) quote Shaw, who in unpublished data, showed that exposure of a patient to pure oxygen for four hours causes a drop in the partial pressure of nitrogen in the arterial blood from 573 to 31 millimeters of mercury The inhalation of a nitrogen free atmosphere reduces the pressure of nitrogen within the lung to near zero The nitrogen in the blood then diffuses into the alveoli to be blown off The resulting decreased partial pressure of this gas in the blood encourages diffusion into it by nitrogen in the tissue spaces and cavities By such a process denitrogenization may be more rapidly accomplished than by breathing room air

Nitrogen may accumulate in abnormal amounts in body tissues and cavities as the result of disease and trauma Many workers have employed high oxygen concentrations to facilitate nitrogen removal from such tissues and cavities Boothby *et al* (71) have shown that the amount of time necessary to wash out the nitrogen from the lungs varies from that in normal subjects under basal conditions of about 2–3½ minutes to 10–12 minutes in patients with marked emphysema

1 INTESTINAL DISTENTION

Singleton Rogers and Houston (358) feel that gaseous distention within the gastrointestinal tract is a real problem and should be actively treated Gatch *et al* (164) state Distention is the most important cause of death from all forms of bowel obstruction mechanical or paralytic and most of the other supposed and suggested causes of death cannot exist in the absence of distention All efforts should be made to limit intestinal distention because of several factors (358) Intraluminal gas pressure results in ischemia of the wall and later congestion which may affect the viability of the wall Stretching of the bowel results in a decreased activity of the nerve mechanism of this structure as well as of muscular contraction and with advanced distention over a long period of time even though the distention is relieved the bowel contraction is delayed resulting in paralytic ileus Not to be overlooked are the changes in blood concentration which have been reported

which are characterized by the loss of blood protein into the peritoneal cavity Schnedorf and Orr (337) believe that distention plays an important role in failure of the liver and kidney Liver function is first impaired by nerve reflex inhibition due to distention of the intestine The anoxemia present in cases of severe intestinal distention may produce a marked impairment in the formation of bile and urine

Rosenfeld and Fine (319) have shown that by causing an animal to breathe pure oxygen instead of air, the volume of nitrogen in a closed loop of small intestine distended with this gas can be reduced in 24 hours to about 10 per cent of its original volume This is in contrast to an average variation of only 10 per cent of the original gas volume when the animal breathes room air for the same period of time These authors showed also that not only is oxygen inhalation an effective means of reducing the intra intestinal pressure but it also prolongs the survival time of cats in which the obstructed small intestine was distended with air or nitrogen

Since the nitrogen content of intestinal gases is up to 90 per cent the partial pressure of nitrogen in the intestinal gas is about 640 millimeters of mercury If the patient breathes pure oxygen the nitrogen tension in the blood will soon drop to zero or close to it Consequently in breathing pure oxygen the difference in pressure whereby nitrogen diffuses from intestines to tissue and blood will be 640 millimeters of mercury When one breathes atmospheric air the nitrogen tension of the blood is about 570 millimeters of mercury and the pressure difference that causes the nitrogen to diffuse from intestine to blood is consequently only about 70 millimeters of mercury By breathing pure oxygen it should thus be possible to increase the nitrogen absorption almost tenfold Since much of the air in the bowel is swallowed air with the patient breathing oxygen only he will swallow oxygen rather than nitrogen Ringsted and Andersen (312) studied the relief of distention by oxygen inhalation They injected portions of rabbits intestines between two ligatures with atmospheric air nitrogen or oxygen The animals were then placed in chambers and exposed to varying concentrations of oxygen In their experiments with pure nitrogen in the closed intestinal loop and with the animal breathing atmospheric air the average absorption from the in

testine over a 24 hour period was 9 4 per cent In the next set of experiments with absorption of nitrogen from a closed loop in an animal breathing high oxygen concentrations there was a seven fold increase in nitrogen absorption with an average of 68 4 per cent removed over a similar interval

If pure oxygen is swallowed or introduced into the intestinal tract in the course of treatment this oxygen will be absorbed more rapidly and more completely than if atmospheric air is swallowed

Other experiments were designed to test oxygen therapy by means of a distention involving the whole or most of the small in testine whereas the previous experiments were on a closed loop Here too the result showed that after 24 hours of oxygen therapy the percentage of absorption agrees fairly well with the values obtained from the experiments with closed loops

These authors conclude that paralytic ileus is one of the chief indications for oxygen therapy They feel that the procedure is indicated even when distention is due to an obstruction where it may be desirable to postpone operation for some reason Inhala tion of high concentrations of oxygen may be indicated in con junction with Wangensteen suction in the treatment of distention Such therapy may also be indicated after intestinal operations as a prophylactic for distention

Fine *et al* (156) treated five cases of paralytic ileus with 95 per cent oxygen which in the period of 24-48 hours brought about such an absorption of gas that intestinal motility was regained Congdon and Burgess (103) by employing the closed box technic developed by them treated 40 cases of abdominal distention Of these 40 25 showed a definite decrease in the distention in five the results were questionable and in 10 the treatment seemed to have had no effect

2 SUBCUTANEOUS EMPHYSEMA

Congdon and Burgess (103) employed the administration of high oxygen for the removal of nitrogen in tissue spaces in three cases of severe subcutaneous emphysema The first was a patient suffering from postpneumonic empyema with a bronchopleural fistula and subcutaneous emphysema The emphysema was severe and this patient received 12 hours of 95 per cent oxygen by inhala

tion She was taken out for five hours and then put back in for another five hours after which time marked improvement was evident The second was a patient with pulmonary abscess who had a thoracotomy Two days following thoracotomy a marked subcutaneous emphysema appeared Twelve hours of 95 per cent oxygen gave her relief After a short interval she was again put back into the oxygen apparatus for another 11 hours The third patient so treated had fractured ribs with subcutaneous emphysema After three 12 hour periods the emphysema had completely disappeared

3 POST AIR ENCEPHALOGRAPHY

Because of the collection of nitrogen in the central nervous system following injection of air for purposes of encephalograms Congdon and Burgess felt that it was necessary here too to denitrogenate the patient rapidly to diminish the duration of headache Their results have been so satisfactory that they feel the method should be employed routinely Their experience was similar to that reported by Schwab Fine and Mixter, in that a marked alleviation of headache occurred (339)

C CONDITIONS DUE TO ALTERATIONS IN ATMOSPHERIC PRESSURE

1 AERO EMBOLISM (*The bends*)

During rapid change from high to atmospheric or from atmospheric to low pressure respiratory gases in blood plasma and tissue are released to collect as bubbles in blood The amount of bubble formation is dependent upon the rate and degree of decrease in atmospheric pressure These bubbles mainly of nitrogen act as emboli and may lodge in the lungs brain heart or in the nerve roots of the spinal cord where their presence cause corresponding symptoms The bends in the elbow knee or ankle are due to collections of gas in the fascial and intermuscular septal planes which cause pain by dissecting to the periosteal insertions of such anatomical layers (264) It is possible that fatal emboli may appear during rapid ascent from as low as 30 feet under water Polak and Adams (301) have shown that in submarine escape training employing a Momsen lung rapid expansion of the intrapulmonary

gases in sailors holding their breath was sufficient to rupture alveolar walls The air under pressure then entered the pulmonary circulation was carried to the heart and then distributed through the systemic circulation

a Compressed Air Illness (*Caisson disease*)

This occurs in individuals such as deep sea divers or workers in caissons who are subjected to prolonged exposure to increased atmospheric pressure Upon rapid reduction of the atmospheric pressure the released nitrogen accumulates and acts as emboli with rapid production of symptoms Ordinarily symptoms are not produced if the heightened pressure was not more than 1¼ times that of the atmosphere Regardless of the degree of original compression aero embolism may be prevented by slow decompression to allow for elimination by respiration of the gases liberated by tissues Decompression should be carried out in stages rather than continuously The air pressure should be halved at each step of decompression Since helium has a co efficient of solubility in blood approximately one half that of nitrogen and is about twice as diffusible deep sea divers kept in such an atmosphere may be decompressed in one third to one fourth the time necessary for air

b High Altitude Aeroembolism

Since the production of gaseous emboli is the result of an acute reduction in barometric pressure a very similar train of events may occur in pilots and air passengers in rapid ascents from the ground as occurs in deep sea divers ascending from great depths A reduction in pressure from one atmosphere to one third of an atmosphere corresponds to a reduction from three atmospheres to one atmosphere Ordinarily in high altitude aeroembolism the emboli cause no more than pain in the large joints Rarely are the symptoms as severe as those which may be seen in deep sea divers However paralysis due to lodgment of emboli in the spinal cord and brain have been reported as have instances of pulmonary edema The occurrence and severity of emboli may be decreased by inhalation by the aviator of 100 per cent oxygen or a mixture of helium 80 per cent and oxygen 20 per cent for a couple of hours previous to flight Breathing such mixtures eliminates nitrogen

from tissue to a large degree It is important however that after breathing this mixture for two hours the aviator continue breathing such an atmosphere during his ascent

2 AERO OTITIS MEDIA

Armstrong and Heim (19) defined aero otitis media as an acute or chronic traumatic inflammation of the middle ear caused by a pressure difference between the air in the tympanic cavity and that of the surrounding atmosphere commonly occurring during changes of altitude in airplane flights and characterized by inflammation, discomfort pain tinnitus and deafness

This condition was first described as a consequence of air flight A similar condition is known by compressed air workers as ear block It is the result of decreased ventilation of the middle ear during changes in atmospheric pressure Normally the air passenger can ventilate his middle ear by such acts as swallowing In the presence of chronic nasopharyngitis sinusitis tonsillitis or inflammation of the eustachian tube voluntary ventilation is not successful The symptoms of poor ventilation may vary from simple fullness in the middle ear to the presence of noises severe pain nausea and vertigo Traumatic rupture of the tympanic membrane has occurred Lovelace Mayo and Boothby (260) have successfully employed helium oxygen inhalation to relieve or prevent this condition

Crosson Jones and Sayers (109) have employed helium oxygen mixtures in the treatment of ear block in compressed air workers A simple apparatus was designed by the United States Bureau of Mines Laboratories which could be used by the worker in the lock while being decompressed This is a simple apparatus consisting of a small cylinder of 80 per cent helium and 20 per cent oxygen connected by means of a reducing valve to a breathing bag The authors state that use of this apparatus prevented tubal and sinus block in a very large percentage of the workers It is not so successful when the block is complicated by inflammation of the eustachian tube or nasal sinuses

D RESPIRATORY TRACT INFECTION

An aerosol is a suspension of a liquid or solid in air or oxygen Each particle of the liquid aerosol is generally 1–2 micra in diame

ter (343) Drugs may be so employed for their bacteriocidal bronchodilating and vasoconstrictor effects

1 AGENTS

a Vasoconstrictor and Bronchodilator Agents

Epinephrine possesses both vasoconstrictor and bronchodilator properties and has therefore been employed in the treatment of asthma Neosynephrine however, possesses very little bronchodilating properties and is of most value in the treatment of emphysema These drugs because of their bronchodilator properties may be of value in irritant gas poisoning (41) Patients who have become refractory to either epinephrine or neosynephrine hypodermically may get no further relief from the topical application of these agents

Aerosol administration of combinations of epinephrine and neosynephrine seem to yield more benefit than does the oral administration of aminophylline and ephedrine (35)

Aerosolized bronchodilating and vasodilating agents are of value in the treatment of chronic infective bronchial asthma after eradication of the underlying organism by penicillin aerosol (343) The topical application of these agents has been employed with pressure breathing in the treatment of asthma silicosis and emphysema with good results (281)

Epinephrine solutions can be made more stable and less irritating by the addition of glycerine (5–25 per cent) (1 256) Abramson (2) employs the phosphate of epinephrine A solution of this agent should preferably be of a pH between four and five and should contain glycerol and some other substance to stabilize the particle size distribution of the mist He states that failure with solutions of this type are often due to

1 Insufficient solution being nebulized
2 Poorly constructed nebulizer
3 Insufficient glycerol or other stabilizing substance
4 An excessive amount of secretion in the bronchial tree preventing access of the aerosol to the points required

b Bacteriostatic Agents

Agents have been aerosolized into the pulmonary tree for their bacteriostatic effects Nebulized prontosil for the treatment of

bronchiectasis was employed in 1941 (90), sulfathiazole was nebulized by compressed air for the treatment of respiratory tract infection in 1942 (92 362) Other drugs that had been used in the treatment of bronchopulmonary infection include sulfadiazine 2 5 per cent in ethanolamine solution neosynephrine sulfathiazolate, Promin(R) (glucosulfone sodium) and sodium sulfathiazole The inhalation of sodium sulfathiazole is perhaps the best of these since it is a readily soluble drug and has not been found to be unduly irritating If a one per cent solution of this agent is employed it should be in normal saline If solutions of five per cent or stronger are employed they should be dissolved in distilled or tap water A possible complication of sulfathiazole aerosol therapy is exfoliative dermatitis In aerosolizing sodium sulfathiazole a rebreathing bag should not be employed since the exhaled carbon dioxide may precipitate the drug by lowering the alkalinity of the solution (31)

The inhalation of nebulized solutions of Promin(R) prevented the development of experimental tuberculosis in guinea pigs (39) Edlin *et al* (140) reported on the use of nebulized Promin(R) in pulmonary tuberculosis in 1944

Streptomycin alone and in combination with penicillin has been employed (35 291 292) Streptomycin has been recommended in a concentration of 0 02 gram to 0 05 gram streptomycin per cubic centimeter and in combination with penicillin consisting of 200 000 units of penicillin and 0 5 gram or one gram of streptomycin in 20 to 30 cubic centimeters of isotonic sodium chloride solution (292) Streptomycin in combination with penicillin seems to be more effective than pencillin alone (291) Streptomycin by aerosol and hypodermically is credited with a remarkable cure of isolated laryngeal tuberculosis (154)

Bryson Sansome and Laskin (78) suggested the use of penicillin as an aerosol Since penicillin is known to be potent in extremely high dilutions inhibiting the growth of streptococci in solutions as low as 0 1 microgram per cubic centimeter it has found an important role in the topical treatment of infections (41) Although the lung has a wide surface for absorption aerosols are administered for their topical effect primarily The use of blood levels or the amount recovered in the urine are not indices for the effectiveness of aerosol therapy whereas hypodermically the use of such drugs

may result in higher blood concentrations and larger amounts may be recovered in the urine, but the local effect of drugs so administered may be insignificant Topically applied by aerosolization however the greatest concentration of the drug is at the area to be treated and consequently blood concentrations are low and the amount recovered in the urine may be small

Bryson *et al* (78) in their first published use of penicillin aerosol in animals and man state

1. Penicillin solution was not altered to any extent by the gas flow incidental to nebulization
2. The penicillin formed an aerosol that was readily recovered with no sensible loss of activity
3. Penicillin aerosols readily penetrated the lungs of animals and man
4. Penicillin could be recovered from the lung tissues of animals treated with penicillin aerosols
5. Penicillin aerosols diffused from the respiratory tract into the blood stream
6. Recovery of penicillin from the urine of human volunteers was readily accomplished
7. As much as 250 000 units of penicillin per cubic centimeter could be nebulized and inhaled without lung injury

The excretion of penicillin in the urine during a 24 hour period following inhalation of the aerosol varies between 10 and 20 per cent of the total amount administered This is in contrast with the 60 per cent recoverable in the urine when it is given by intra muscular injection Barach *et al* (41) state However the per centage *of penicillin found in the urine is an index of the amount* absorbed rather than the effectiveness of aerosol administration In infection of the pleural cavity penicillin by systemic injection is not curative whereas local instillation may be followed by re covery Similarly in lung abscess the penetration of the aerosol into the cavity may be of special value in limiting the growth of organisms

Considerable attention has been given to the particle size of aerosols Large particles may act as foreign bodies (306) initiating the cough reflex with expulsion of the droplets Findeisen (155) states that particles of 3 micra and above are taken out completely

by the trachea the bronchi the bronchioles and the alveolar ducts Particles of one micron radius and above are taken out by the lungs to the extent of 97 per cent with only 3 per cent recovered on expiration As the radius of the particle gets smaller particles of 0 3 micron in radius are absorbed to the extent of only 35 per cent

Since satisfactory aerosolization depends upon satisfactory particle size distribution it is important to maintain a reasonable percentage of particles inspired above a given critical radius Abramson (2) gives two essential factors which control the particle size and persistence of mists They are 1) the vapor pressure of the droplets and 2) the surface tension of the droplets It has been shown that agents which lower the vapor pressure of the droplet sufficiently produce a more stable mist For this reason glycerol urea, sugar and salt have been added to aerosols All of these act to stabilize the mist by lowering the droplet vapor pressure If stronger solutions of penicillin are nebulized it is unnecessary to add such agents because the penicillin itself apparently acts to stabilize the particle size distribution The behavior of streptomycin in strong solutions is similar to that of penicillin With hydrogen peroxide ten per cent of glycerol is sufficient

Prigal *et al* (307) recommended that aerosols can be made more stable by the addition of propylene glycol The addition of 1 cubic centimeter of glycerine to the propylene glycol penicillin stabilizes it further Propylene glycol is a good solvent for penicillin and it has bacteriocidal properties of itself

Vermilye (383) employed penicillin aerosol with good results in various upper respiratory infections—pharyngitis tonsillitis sinusitis sinobronchitis pneumonitis and intrinsic bronchial asthma Segal (343) however has observed simple colds become worse under this form of therapy Segal employs aerosol penicillin in bronchopneumonia bronchiectasis and lung abscess infective bronchial asthma and patients with pneumococcus pneumonia

Hanks (197) has employed it in bronchiectasis chronic bronchitis subacute bronchitis acute bronchitis tonsillitis and laryngitis It has been employed preoperatively and postoperatively in pulmonary surgery with satisfactory results It was employed in 46 cases of chest surgery preoperatively (292) and in the treatment

of pneumonia due to penicillin susceptible strains of Friedlander's bacillus (346)

Prigal *et al* (307) state Results have shown that the inhalation of aerosols of penicillin produces a concentration of the drug sufficient to make it effective for treatment not only of bronchopulmonary disease but also of infections in other systems of organs in which use of this antibiotic is indicated

Olsen (290 291, 292) found that the use of penicillin aerosol preoperatively reduced the volume of pulmonary secretions considerably in the majority of instances When preoperative nebulization has been effective additional bronchoscopic aspiration for the relief of pulmonary atelectasis has been required only infrequently Results in the treatment of patients with bilateral bronchiectasis were considered satisfactory if the daily volume of purulent secretions was reduced 75 per cent or more In 19 of 40 patients penicillin aerosol did not reduce the daily volume of sputum to one fourth of its previous volume In 21 instances satisfactory reduction in volume of sputum was obtained When penicillin was combined with streptomycin as an aerosol however of 20 patients treated 18 obtained a satisfactory reduction in sputum The risk of operation was decreased in all cases by this form of therapy There was less difficulty in the handling of bronchial secretions during and after operation Those in whom lobectomy was performed in the presence of bilateral bronchiectasis experienced a minimum amount of difficulty in the postoperative period This was in marked contrast to their previous experience after the surgical treatment of bilateral bronchiectasis

Olsen (290) found that in most cases it is much easier to effect a reduction in the amount of sputum by nebulization with penicillin than by the subcutaneous administration of the drug He states categorically that preoperative and postoperative treatment by the use of penicillin aerosol is far superior to treatment with oral or parenterally administered sulfonamides

Segal and Ryder (317) report that of 32 patients effective clinical cures were obtained in seven with pneumococcus pneumonia and in one with acute pulmonary infarction and pneumonitis Ten patients with bronchiectasis were satisfactorily treated two preoperatively followed by lobectomies and eight entirely medically

Four patients with lung abscess were treated one with a fulminating putrid lung abscess died on the fifth hospital day following surgery a second was prepared for uneventful lobectomy, a third was entirely cured with six weeks of therapy and a fourth with multiple lung infarcts and lung abscess improved slowly but completely These authors were not impressed with the clinical effect in 10 patients with severe chronic infective bronchial asthma

Segal *et al* (316) treated patients with severe chronic infective bronchial asthma with generally disappointing results although improvement was occasionally observed In regard to the treatment of pulmonary abscess they conclude that penicillin is of value in the aerobic non odoriferous post pneumonic type of abscess and that results with the anaerobic putrid types of abscess are disappointing

There have been reported a considerable number of untoward effects from penicillin aerosolization It is generally felt that the calcium salt is less irritating than the sodium salt for this purpose Inhalation of penicillin aerosol in a concentration of 50 000 units per cubic centimeter or more produced in some patients a sore throat and sore tongue as well as an occasional substernal soreness Rinsing of the mouth and gargling the throat after penicillin aerosolization tends to prevent the local irritating effect Concentrations of 10 000 units per cubic centimeter are preferable There seems to be some evidence that there is less irritation by penicillin aerosol made with saline than that dissolved in distilled water alone Abramson and Kolb (3) state that Dundon reports an instance of pulmonary edema which developed under treatment with a combination of penicillin and hydrogen peroxide aerosol This is probably an allergic response to the penicillin Three cases of urticaria in two associated with a mild arthralgia and three patients with a sore tongue are reported (292) Several patients developed a sharp rise in temperature and a chill after the administration of streptomycin by inhalation

Pyribenzamine or benadryl may be used in the treatment of urticaria which may follow the adminstration of penicillin Dyspnea has been noted as an allergic response to penicillin aerosol Patients may at times develop swelling of the bronchial mucosa which is apparently an irritant or allergic response In patients

with bronchospasm, inhalation of a dense nebulized mist may produce increased wheezing (35) Barach (31) noted that in many cases of bronchial asthma the development of an allergic response to penicillin had interrupted therapy at a time when apparently favorable results were being obtained Urticarial responses occur more frequently in asthmatic patients than in non allergic individuals

Hydrogen peroxide has been combined with penicillin in aerosol therapy of pulmonary disease It may be readily nebulized and in bactericidal concentrations is not irritating to pulmonary tissues Abramson (2) believes that this is a method of approach for the destruction of both gram positive and gram negative organisms In most of the cases under study penicillin was administered for two to four days followed by 3 per cent urea peroxide plus 10 per cent glycerol dissolved in physiological saline for two days It is important to gargle immediately after the administration to minimize sore throat The preliminary results in the non tuberculous lung infections indicate that this combined antibiotic therapy may be an important technic in handling chronic suppurative disease Hydrogen peroxide is not as effective alone as when used alternatively with penicillin Abramson treated two cases of chronic pulmonary tuberculosis without material clinical improvement except for some relief from paroxysmal cough In one instance laryngeal pain was relieved by penicillin aerosol shortly after the beginning of therapy In the course of a month of combined penicillin and hyrodgen peroxide therapy the cough was less forceful with less purulent sputum and a decrease in its viscous quality In a second patient the improvement was the same In both the tubercle bacillus persisted in the sputum and on smear and culture

It has been stated (306) that ammonium chloride is of help in dissolving tenacious mucus plugs when there is an associated bronchiectasis or bronchitis existing along with asthma and that preliminary treatment with a mixture aerosol of aminophylline and ammonium chloride when followed by penicillin aerosol is satisfactory

Krasno *et al* (237) have recommended the inhalation of penicillin dust in the treatment of infection of the respiratory tract They treated patients for the following conditions rhinitis naso

pharyngitis sinusitis laryngotracheobronchitis bronchiectasis bronchitis bronchial asthma pneumonia and pulmonary abscess They were able to demonstrate that there was a decided reduction in the number of or complete disappearance of gram positive bacteria In many instances there was a decided decrease in the number of gram negative bacteria Results from the inhalation of penicillin dust were gratifying for varying degrees of improvement were shown in all cases of bronchiectasis Patients with bronchial asthma and chronic bronchitis had moderate to decided improvement Patients with asthma of bacterial origin improved remarkably Those with acute rhinitis or laryngotracheal bronchitis usually recovered completely within one to three days Eastlake (133) however found that penicillin as dust produces more numerous and more severe local reactions than in aerosol form

2 APPARATUS

For the development of a mist or aerosol it is necessary that oxygen helium oxygen or air be passed over a fine orifice leading from a chamber containing a solution of the drug to be employed Steam has also been recommended (307)

Air may be delivered by hand bulb This is the common method for the use of vasoconstrictors or bronchodilators by inhalation Air may be delivered to the nebulizer by means of a foot pump (40) Air is not only more economical than oxygen but this means of nebulization may be of advantage for home use In the treatment of sinusitis (40) an incidental advantage of air over oxygen is the fact that the rapid absorption of oxygen from the eustachian tube will produce a slight negative pressure with discomfort

For all methods of aerosolization there are hand nebulizers so constructed that particles of proper size are delivered (Figure 23)

The delivery portion of the nebulizer may be inserted into the patient s mouth or attached to an endotracheal or a tracheotomy tube Aerosol oropharyngeal insufflation by catheter has been recommended for infants and small children (41) One may question the delivery efficiency of a mist through the ordinary catheter because of condensation The method is not recommended for adults

If the solution is being constantly nebulized much is wasted during the expiratory phase To obviate this a Y tube is placed into the tubing delivering compressed oxygen or air Placement of

a finger or thumb over this Y tube during inspiration nebulizes the solution Upon removal of the finger from the Y tube during the expiratory phase of respiration the gases are diverted from the nebulizer

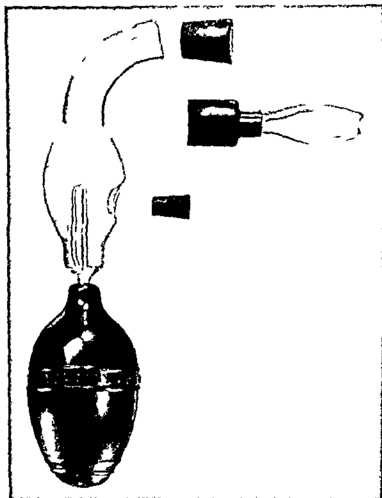


Figure 23 Hand bulb for aerosolization

In order to avoid waste the aerosol may be intermittently delivered by the use of a demand valve (35 345 346) Here the aerosol is delivered only during the inspiratory phase of respiration for only during this phase are gases delivered from the demand system

During exhalation the expired gases carry off a considerable portion of the aerosol To conserve this a rebreathing bag attached to the apparatus has been recommended (Figure 24) Some



Figure 24 Aerosol by rebreathing bag

have recommended that the aerosol be conserved by exhalation into a glass cylinder so that the aerosol will condense and return to the nebulizer (26 41 348) Rebreathing of gas mixture is not without hazard Carbon dioxide accumulates in the bag or chamber Carbon dioxide is not well tolerated by the ill or dyspneic patient suffering from pulmonary or cardiac disease This method then should not be employed

It has been recommended that the mist be delivered in conjunction with inhalation therapy by means of a face mask into which the nebulin is administered (35 343) Such therapy however is not efficient for much of the mist will condense on the walls of the mask and about the patient s nose and mouth

Aerosols have been administered by injection into a head hood (35) an air tight chamber (307) or by means of a breathing box (307) In this latter method the patient breathes by mask from a box filled with an aerosol penicillin propylene glycol mixture



Figure 25 Aerosol by the use of the Pneumatic Balance Resuscitator

Directional valves are incorporated into the apparatus so there is no rebreathing

Since as ordinarily employed aerosol therapy is dependent largely upon the inspiratory effort of the patient to carry the aerosol into his lungs and since under some conditions adequate dissemination of the aerosol may be prevented because of obstruction emphysema and fibrosis Motley *et al* (281) developed a method for the intermittent delivery of the aerosol by positive pressure They employed the Pneumatic Balance Resuscitator (P B R) The aerosol was delivered into the system by a separate

take off tubing from the reducing valve (Figure 25)

Convinced that under ordinary methods of aerosol therapy, the mist does not enter the sinuses, an apparatus has been designed for the treatment of sinusitis which intermittently develops nega tive pressure in the nasal passages followed by replacement of air containing penicillin in high concentrations (28 36 37, 133) Segal *et al* (316) feel however that penicillin gets into the sinuses by way of the veins and lymphatics in the mucosal linings of the nose, rather than by way of the ostia

The apparatus recommended by Krasno *et al* (237) for the in halation of penicillin dust consists of a plastic mouthpiece a con tainer of penicillin dust powder which has been processed to 50 to 100 mesh and a discharge control mechanism The discharge control mechanism is actuated during inspiration An aluminum ball strikes the container of penicillin dust discharging some of its content into the air stream The dosage employed is 100 000 units of penicillin dust one to three times daily

3 DOSAGE

Penicillin Penicillin is employed in a concentration of 25 000 to 40 000 units per cubic centimeter of saline This is in general administered every three hours For the pre and postoperative care of patients with bronchiectasis it is recommended that this therapy be carried out seven days before and seven days after the operation For the medical treatment of bronchiectasis six weeks treatment is recommended followed by a period of rest and then another six weeks period Satisfactory results may require several courses of such treatment

Vasoconstrictors One cubic centimeter of one per cent neo synephrine or 0 5 cubic centimeter of 1 100 epinephrine are rec ommended

Streptomycin This drug is recommended in about the same dosage as penicillin 0 02 to 0 05 gram per cubic centimeter of saline In combination with penicillin 0 5 gram of streptomycin is employed in 10 cubic centimeters of normal saline to which has been added 100 000 units of crystalline penicillin

Sulfadiazine This agent is recommended in a 2 5 per cent solu tion

E MISCELLANEOUS INDICATIONS

1 MIGRAINE

Oxygen has been recommended for the treatment of migraine Alvarez (8) Alvarez and Mason (9), as well as Pfeiffer (297) have had good results with the administration of high concentrations to people early in attacks of migraine They believe that if oxygen is given early enough the attack can be aborted Alvarez (7) speaks of a patient who had relief from the inhalation of oxygen after Gynergen had failed Alvarez and Mason (9) graded the results obtained with oxygen inhalation They found that 62 per cent of patients obtained some relief 37 per cent had not been helped and one per cent were made worse They are convinced that the patients with migraine headaches got good relief whereas those with non migrainous headaches did not Of the patients who had *migraine 80 per cent were relieved Another 8 per cent were some*what relieved and 12 per cent continued unchanged They conclude that although oxygen is worth trying in cases of non migrainous headaches the best results are to be looked for in cases of typical migraine and oxygen appears to work as often as does Gynergen On the other hand some patients who respond well to Gynergen do not respond to oxygen In some the headache was relieved within 15 minutes after beginning to breathe the oxygen Some lost their nausea within the first half hour but continued the therapy for an hour or two before relief of the headache was obtained

A possible mechanism for the effect of oxygen in relieving headache is the following Dille and Horton (120) feel that migraine is a vasodilating headache The inhalation of high oxygen concentrations leads to a 12 per cent decrease in cerebral blood flow (232) The cerebral vascular resistance calculated from the cerebral blood flow and direct mean arterial blood pressure was increased by oxygen inhalation

2 WHOOPING COUGH

Kohn *et al* (236) demonstrated that oxygen inhalation has a favorable influence on the course of whooping cough and state Oxygen is believed by us to be the most valuable therapeutic aid

for all severely ill infants and young children who have some degree of anoxia This anoxia is mainly due to 1) the character of the mucoid secretion plugging part of the bronchial tree causing varying degrees of atelectasis 2) extensive pulmonary involvement with or without atelectasis, and 3) frequent long exhausting paroxysms They place every young infant on admission in an oxygen tent or hood The therapy is maintained from 24 hours to six weeks They note that children who had exhausting paroxysms without evidence of pneumonic infiltration were often relieved when placed in this high oxygen atmosphere It seemed to act as a sedative for the child fell asleep and the paroxysms became less prolonged and exhausting The temperature of the hood was kept at about 68° Fahrenheit humidity at about 40 per cent and the oxygen concentration at about 50 per cent Oxygen therapy proved to be a valuable aid in children who had convulsions Many such patients were relieved quickly and were kept in oxygen tents or hoods until there was no further evidence of cerebral irritability

It has been pointed out by Fischer (158) that there are special circumstances in infancy and childhood which hasten the development of hypoxia in the presence of respiratory and infectious diseases of childhood such as measles and pertussis These special circumstances are 1) the narrow caliber of the larynx and bronchial tree which become easily obstructed 2) the inability to expectorate and 3) the character of the bronchopulmonary pathology in respiratory diseases and in the respiratory complications of certain infectious processes

An inflammatory reaction in the larynx and tracheobronchial tree is associated with production of secretions This leads to obstruction and interference with ventilation with resultant dyspnea Efforts to increase the depth of respiration by producing an increase in negative intrapulmonary pressure increases the production of exudate and aggravates bronchial obstruction with a tendency for the development of patchy atelectasis

Oxygen therapy is important and for these children the cheapest and easiest method is by means of the Burgess open box to be later described Maintenance of a high degree of humidification is important A fine jet spray of water into the apparatus is of value

Saline should not be used for humidification as the salt has a tendency to crystallize and may therefore obstruct the tube

In whooping cough oxygen is needed most frequently in the youngest patients Fischer (158) states In fact, almost every infant under six months of age will benefit by its use even though he be afebrile Paroxysms are less frequent if the infant is kept in oxygen Following a paroxysm there may be a long period of apnea and cyanosis and oxygen is especially needed at this time The paroxysmal stage of whooping cough may last from two to four weeks and it should not be unusual to keep infants in an increased oxygen atmosphere for much of that time

If cerebral involvement occurs oxygen is of especial value Dolgopol (121) has called attention to the role of hypoxia in the etiology of cerebral involvement

3 PULMONARY EMBOLI

De Takats and Jesser (119) have shown that pumonary embolism causes marked bronchial constriction through vagal effects Such bronchical constriction may cause severe and often fatal interference with oxygenation of the patient Many agree with Allen (5) that oxygen has an important role in the therapy of this condition

4 HICCOUGH

Carbon dioxide has been recommended in the treatment of hiccoughs The hazard of respiratory acidosis associated with its administration should be emphasized

5 NEONATAL MORBIDITY

Much has been written about the value of oxygen administration for the relief of oxygen want occurring in the fetus especially during labor Oxygen administration to the mother may even be indicated before the infant is born Anything which may reduce the oxygen content of maternal blood may lead to fetal hypoxia When disease occurs during pregnancy Beck (53) states that some of these fetuses might be saved by more frequent use of oxygen in the treatment of *pneumonia as well as in the treatment of decompensation* and cardiac disease Potter (302) notes that oxygen want

is the highest single cause of infant death (28 7 per cent of 1,173 deaths)

Hypoxia may be produced in the fetus because of prolonged pressure of the head on the pelvic floor by interference with the circulation to the cord thereby preventing adequate oxygenation of the fetal blood in the placenta, and most often by the excessive use of analgesic and anesthetic drugs to the mother (200) A very valuable criterion of fetal embarrassment in labor is the fetal heart rate When the rate falls to 100 or less between contractions this usually means oxygen want in the fetus Administration of 100 per cent oxygen to the mother between uterine contractions will restore the fetal heart rate to normal unless compression of the cord is present

Torpin (377) states that among the conditions which reduce oxygenation of the maternal blood stream are convulsions or coma of eclamspsia pneumonia and other infections anemia cardiac decompensation and the use of anesthetics Inability of the fetus to obtain oxygen may be the result of conditions such as premature separation of the placenta placenta previa cord compression or prolapse of the cord Torpin thinks that if oxygen were administered to all eclamptic patients in convulsions or coma there would be a resultant augmentation of the salvage rate of the fetuses

6 PREMATURITY

The value of oxygen administration to the premature infant has been well stated by Smith (360) Although there is no mathematical basis for measuring the beneficial aspect of this form of therapy benefit can be demonstrated clinically There is much evidence that the pulmonary circulatory and central nervous systems of premature infants are exceptionally vulnerable Crises of a respiratory nature which appear very often in these individuals and which are relieved by oxygen administration leave no doubt that the therapeutic endeavor is worthwhile

The arterial oxygen saturation of premature infants may be considerably below a satisfactory level Atelectasis or left to right vascular shunt may be present Even in premature infants free of pulmonary or circulatory conditions and in whom the arterial oxygen saturation may be normal respiration is usually irregular or

periodic Smith (360) demonstrated that the administration of oxygen to these children not only relieved the characteristically irregular respiration but also increased ventilation by as much as 25 per cent

These patients should be given oxygen continuously One must not forget that there is such a thing as oxygen poisoning There is however some reason to believe that the pulmonary lesions of oxygen poisoning are less likely to occur in the newborn than in the adult

It is known that anemia regularly occurs in premature infants It should be of some concern whether prolonged oxygen administration diminishes the stimulus to erythrocyte and hemoglobin formation Smith believes that such therapy does not affect hemopoiesis

At the Boston Lying in Hospital every premature infant is placed in 40–50 per cent oxygen for at least 24 hours after birth *Infants are not permanently removed from this until the color* activity and respiration remain satisfactory in a normal atmosphere As a general rule infants of two pounds birth weight are not removed until they have gained at least one pound and are continuing to gain This may require residence in a high oxygen atmosphere for about two months Two to three pound babies are kept in oxygen for five to six weeks and the three to four pound infants for three weeks

7 LARYNGOTRACHEOBRONCHITIS

Davison (117) reported a series of 52 consecutive cases of laryngotracheobronchitis There were no deaths in their series Among the factors which contributed to this negligible mortality was the administration of oxygen in a cool atmosphere The importance of aspiration and postural drainage and the use of tracheotomy when indicated was pointed out Humidification plays a great role in the care of these individuals Davison states that humidity helps greatly to maintain the fluidity of the tracheobronchial secretions

8 POST BRONCHOSCOPIC CARE OF CHILDREN

Laryngeal edema particularly of the sub glottic type occasionally follows bronchoscopy even in the most experienced hands

A small amount of edema in a youngster can cause severe respiratory obstruction A certain percentage of these cases require tracheotomy In laryngeal edema inhalation therapy is of value Hart and Davis (202) have employed oxygen therapy under these circumstances with good results

9 HEAT EXHAUSTION

The characteristic feature in individuals who are prostrated because of heat is circulatory failure The patients are in a state of shock Herein the use of high oxygen concentrations is of value because of the increased saturation of the plasma which results The patient s circulatory efficiency is decreased and it is important to attempt to maintain the oxygen requirements of tissue by such means

10 HEAT RETENTION

The characteristic feature of this condition is the patient s high temperature These patients differ markedly from the group above The patient s metabolic requirements are high and great oxygen deficit occurs The administration of oxygen in high concentrations to these individuals is a very important part of therapy (73)

11 HEAD INJURIES

It has been shown by Lindquist and LeRoy (253) that there was a decrease in oxygen consumption of the brain following head injuries Within one hour after trauma to dogs brains there was an average decrease of 24 per cent in cerebral oxygen consumption and of 17 per cent in cerebral blood flow The administration of 100 per cent oxygen in the course of the experiment caused no appreciable change in cerebral oxygen consumption Others (336 349) however believe that oxygen therapy in head injuries is of great value

Schnedorf *et al* (336) studied the effect of head injury on the arterial blood oxygen In animal experimentation concussion was followed by a decrease in the percentage saturation of hemoglobin from 9 3 to 37 4 per cent below normal The administration of oxy

gen to these animals produced an increase in the percentage saturation

Arterial samples from 12 patients with recent head injuries showed the oxygen saturation to be normal in two, depressed 6–10 per cent in seven 11 per cent in one and 34 per cent and 44 per cent in each of the other two patients

This study showed that hypoxia may be an accompaniment of head injury The drop in arterial oxygen tensions shown may of itself be sufficient to increase the gravity of the condition and lessen the patient s chances of complete recovery Inhalation therapy is certainly indicated in this class of patients

12 ECLAMPSIA

Nicodemus (287) stresses the fact that hypoxemia is not at all an unusual finding in patients with eclampsia Associated with this state of oxygen deprivation of tissue is a tendency toward acidemia with the development of acidosis There is a rise in arterial and alveolar carbon dioxide Many believe that most of the deaths of patients with eclampsia are the result of cardio respiratory failure It has been said that one third of eclamptic patients who die suffer from pulmonary edema

The oxygen want is apt to be severe with evidence of cyanosis dyspnea restlessness delirium and coma There would seem to be no question that inhalation therapy with oxygen would be of great value Nicodemus claims that oxygen inhalation would relieve the high alveolar carbon dioxide It is difficult to understand how this would be accomplished without increasing the patient s tidal exchange by artificial means This latter procedure would better wash out carbon dioxide than simply exposing the patient to high oxygen concentrations

Nicodemus in treating 13 patients with eclampsia by oxygen inhalation was impressed by the rapidity with which the patients recovered consciousness and became rational There was an earlier subsistence of restlessness delirium cyanosis and dyspnea than he had ever witnessed before this type of therapy was instituted Of the 13 patients 3 had severe pulmonary edema They were relieved by oxygen therapy and ultimately recovered He was further impressed with the reduction in convulsive seizures

F INDICATIONS FOR CARBON DIOXIDE

The inhalation of carbon dioxide has been recommended and employed for many purposes Among these are 1) for replacement 2) for its effect on respiration 3) for its effect on circulation, and 4) for mental conditions

1 FOR REPLACEMENT

It was Mosso s concept that oxygen want is associated with loss of carbon dioxide and loss of bicarbonate from the blood, with an ensuing tendency to alkalosis (acapnia) because of hyperventilation (Figure 3) Hyperventilation is not unusual in clinical practice and may occur as a result of intense emotional experience hysteria diffuse encephalopathy, and as reactions to anesthesia and other drugs (394) Engel *et al* (116) classified the symptoms of hyperventilation as cerebral and peripheral The former consist of various degrees of diminishing consciousness light headedness dizziness giddiness etc Syncope may follow as may complete unconsciousness The peripheral sensory symptoms are numbness tingling a feeling of tightness tetany or even clonic movements Associated with the above symptoms may be such other reactions as sweating cold clammy skin tachycardia muscular weakness fatigue etc

Mosso s experiments in the low pressure chamber indicated that concentrations of carbon dioxide (2–5 per cent) increased the resistance of his experimental subjects to lowering of the barometric pressure Yandell Henderson (205) was much concerned about the acapnia described by Mosso He states Acapnia in turn tends to intensify the deficiency of oxygen for it depresses respiration and renders the blood less ready to give up oxygen in the tissues Because of this Henderson and Haggard (208) believed that carbon dioxide should be administered to recall alkali from tissues into the blood They recommended the inhalation of 5–10 per cent mixtures of carbon dioxide in oxygen Such inhalation would of course be of value only if real carbon dioxide loss occurred This carbon dioxide loss is characteristic of some forms of atmospheric hypoxia The forms of hypoxia most often met in clinical disease however are tidal and alveolar In these there is no carbon dioxide loss In fact there is carbon dioxide retention (Figure 4)

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were given 6 per cent oxygen, 5 per cent carbon dioxide and 89 per cent nitrogen all subjects recovered their normal intellectual functions and the disturbed activity of the cortex returned to normal The addition of carbon dioxide always results in a definite increase in the oxygen supply to the brain

2 FOR ITS EFFECT ON RESPIRATION

Carbon dioxide has been most often recommended for its use as a respiratory stimulant in the treatment of oxygen want It must be noted that under ordinary circumstances carbon dioxide is an effective respiratory stimulant, but under states of advanced oxygen deprivation its action becomes reversed and its administration may produce respiratory depression (56)

Gesell *et al* (176) state Simple hypercapnia produced by administration of carbon dioxide increases the hydrogen ion concentration of blood and tissues and lower oxidations other things remaining constant, oxygen lack leads to decreased oxidations and a consequent increased intracellular acidity other things remaining constant, carbon dioxide excess leads to increased intracellular acidity and a consequent decrease in oxidations

Becker (56) has shown that the toxic effect of carbon dioxide is not dependent upon its acid character but upon other properties a specific lethal action on protoplasm coupled with an ability to penetrate cell boundaries with extreme rapidity In the presence of oxygen want the harmful effects of this agent become accentuated The inhalation of a 3 per cent carbon dioxide mixture is followed by a fall in body temperature greater than that observed in oxygen deficiency alone (166) This effect is particularly undesirable in oxygen want because the body temperature has already been lowered by vascular collapse

Carbon dioxide may be of value in the treatment of atelectasis as considered in the section devoted to this subject It is not amiss to re emphasize the importance of the careful administration of carbon dioxide for this condition If carbon dioxide is given with a high oxygen atmosphere say in a 5 per cent carbon dioxide 95 per cent oxygen hyperpnea will develop This period of hyperpnea however will be followed by a period of decreased ventilation

Acapnia may occur in aviators because of hyperventilation due to Atmospheric Hypoxia Here carbon dioxide inhalation has been recommended to replace the carbon dioxide lost in hyper ventilation and because of its effect on the oxygen dissociation curve In spite of the seemingly more positive indication here it is felt that there is at the present time no valid reason for the administration of carbon dioxide to aviators (27)

Gray (183) states a) that carbon dioxide may ameliorate the hypoxia of medium altitudes but less effectively and less econom ically than equal percentages of oxygen b) that carbon dioxide aggravates the hypoxia of high altitudes and because of the hy perpnea interferes with the economic use of the oxygen supply, and c) that the use of carbon dioxide in military aviation is in advisable

The treatment of acapnia should consist of efforts to relieve the hypoxia which is serving as the stimulus for hyperventilation The administration of oxygen would thus lessen the loss of carbon dioxide (56)

It should be noted however, that Gellhorn (165) showed that the effects of breathing 8 to 9 per cent oxygen on the visual in tensity discrimination in man can be either completely removed or greatly diminished by small concentrations of carbon dioxide (3 per cent)

Gellhorn (168) believes that if the effects of acapnia which may occur in some forms of oxygen want are prevented by the inhala tion of carbon dioxide together with the oxygen nitrogen gas mix ture in experimental animals the blood pressure rise and respira tion are markedly increased over and above the values obtained in pure oxygen deprivation without the carbon dioxide He found that the carbon dioxide makes hypoxia a more powerful stimulant of the sympathetico adrenal system than is oxygen want per se This would seem to indicate that a moderate retention of carbon dioxide elicits more powerful adjustment reactions to oxygen want than does oxygen lack alone This seems to be borne out by the work of Gibbs *et al* (177) These authors showed that normal subjects inhaling a mixture of 6 per cent oxygen and 94 per cent nitrogen became confused or unconscious However when they

tidal volume and maximum lung volume of these patients He concludes that in the cases studied carbon dioxide therapy following laparotomy had no effect in preventing the crippling of the respiratory system

Carbon dioxide inhalation has been employed in the treatment of carbon monoxide poisoning as noted previously because it is a respiratory stimulant and because it hastens dissociation of carbon monoxide from hemoglobin This has been considered in the section devoted to this subject It may be repeated that there is no conclusive evidence that carbon dioxide is of value Indeed it has been shown that it may be harmful

Carbon dioxide has been recommended in the treatment of acute alcoholism to increase elimination of the toxic agent by hyperventilation Its use in narcotic poisoning should be seriously questioned since here too the circulatory effects may outweigh any advantage to be gained by hyperventilation Its use in resuscitation is open to the same objection

Carbon dioxide has been recommended in the treatment of hiccough It may be of value here Too often however uncontrollable hiccoughs occur postoperatively in patients whose general condition is such that carbon dioxide inhalations may be harmful

This agent has been recommended in the treatment of asthma for its effect in liquefying secretions Segal (344) recommends the use of either carbon dioxide oxygen mixtures or carbon dioxide helium oxygen mixtures in patients with asthma for in these patients there is frequently encountered a dry irritating non productive or poorly productive cough and that every attempt should be made to reduce the viscosity of the exudate Some have found that inhalations of carbon dioxide and oxygen are superior in therapeutic action to expectorants (20, 21 48 49) Carbon dioxide oxygen mixtures should be employed with caution only if the more conservative measures have failed and if there are no contraindications to its use

Segal (344) has found mixtures of five per cent carbon dioxide 20 per cent oxygen and 75 per cent helium of particular value when employed to nebulize mixtures of neosynephrine vaponefrin

because of washing out of alveolar carbon dioxide and probably some lowering of the arterial carbon dioxide content An associated factor is that a high oxygen concentration will be left within the tracheobronchial tree This oxygen is readily absorbable and further atelectasis may follow It has been recommended that carbon dioxide be given from a cylinder of 100 per cent carbon dioxide Such a toxic agent should be given with care It is best given by a tube leading from a cylinder of carbon dioxide with the tube held in the region of the patient s face and the patient s respiration carefully watched When hyperventilation occurs the administration of this gas is stopped By this means the patient will get enough carbon dioxide to develop hypercapnea and no large volume of readily absorbable gas will be left deep in the alveoli

Beecher (58) has reviewed the effect of carbon dioxide on the aeration of the lungs of patients after operation He studied the effect of laparotomy in producing crippling of the respiratory function Such crippling of respiration he notes is the result of a) marked reduction in tidal air b) sharp increase in the respiratory rate c) a slight not significant change in total ventilation d) rapid shallow type of respiration e) great reduction in complemental air which is greater following upper than lower abdominal operations f) great reduction in supplemental air greater following upper than lower abdominal operations in men but not in women g) about the same degree of crippling of the mechanism of forced inspiration and of forced expiration h) great reduction in vital capacity following upper abdominal operations and i) marked decrease in sub tidal lung volume and in maximum lung volume

Because of these facts Henderson *et al* (210) had recommended the use of carbon dioxide postoperatively Beecher studied 50 cases in an attempt to determine whether the treatment of patients after operation with carbon dioxide inhalation was of value Of these 50 patients 22 received carbon dioxide after laparotomy and 28 did not Of the patients who received carbon dioxide one half rebreathed their own carbon dioxide through an 8 foot tube three times daily The other half received carbon dioxide from a tank through a face funnel He studied the tidal air vital capacity sub

Lorenz and Waters (258) determined that the administration of high carbon dioxide mixtures to catatonic patients was followed by brief periods of mental clarity

Because of the convulsive effect of carbon dioxide, or for its specific effect on the brain tissue this agent has been used in the treatment of mental diseases as have been other convulsants such as metrazol [illegible] electric shock high nitrogen or nitrous oxide mixtures

or isuprel By such means he has found that a harsh useless ineffective cough may be converted into a useful one

3 FOR ITS EFFECT ON CIRCULATION

Carbon dioxide has been recommended in the treatment of angina and for the treatment and prevention of shock (204) Carbon dioxide inhalations are not free of subjective sensations Even normal individuals are conscious of labored respiration when breathing even low concentrations of carbon dioxide To the person suffering from circulatory disease this added effort may be unbearable let alone being harmful In the presence of passive congestion or pulmonary edema inhalations of carbon dioxide are definitely contraindicated (70)

Drinker and Shaughnessy (130) are not so fearful of carbon dioxide and claim that beneficial effects may be obtained by the increased dilatation of the blood vessels of the heart permitting improvement in the oxygenation and nutrition of that organ Campbell and Poulton (86) suggest that patients with heart failure seem to be more sensitive to carbon dioxide than are normal individuals

4 MENTAL CONDITIONS

Paul Bert had observed that inhalation of high carbon dioxide concentrations can produce unconsciousness This effect has been frequently noted and reported by many observers It has been determined that carbon dioxide in concentrations of 10 to 20 per cent resulted in vagal respiratory and vasomotor stimulation In concentrations of over 20 per cent a state of depression or anesthesia may be obtained Leake and Waters (214) found that the administration of 40 per cent carbon dioxide further depressed respiration and circulation with ultimate apnea Increased muscle tonus or even convulsions can occur with relatively low concentrations of carbon dioxide in some individuals The tendency to convulse is greater if such administration is carried out in patients who are already acidotic (271)

Lennox (245) by the administration of high concentrations of carbon dioxide was able to stop epileptic seizures Loevenhart

TABLE 5

Cylinder size and content of various gases

Cyl Size	*Approx Dimen (Overall)*	*Approx Wt*	*Content*	*Oxygen*	*Carbon Dioxide*	*Helium*	*Carbon Dioxide & Oxygen*	*Helium & Oxygen*
A	2¾ x 10⅝	3 lbs	Gal	17	40	15	17	15
			Cu Ft	2 27	5 35	2 00	2 27	2 00
			Liters	64 34	151 40	56 77	64 34	56 77
			Wt. Gas (lbs)	25	625	0206		*
B	3½ x 16	7 lbs	Gal	40	100	28	40	29
			Cu Ft	5 35	13 37	3 74	5 35	3 87
			Liters	151 40	378 50	105 98	151 40	109 76
			Wt Gas (lbs)	50	1 5625	0625		
D	4 x 20	12 lbs	Gal	95	250	80	95	82
			Cu Ft	12 70	33 42	10 69	12 70	10 96
			Liters	359 57	946 25	302 80	359 57	310 37
			Wt Gas (lbs)	1 0625	4 00	125		
E	4 x 30	15 lbs	Gal	165	420	131	165	134
			Cu Ft	22 06	56 15	17 51	22 06	17 01
			Liters	654 52	1589 7	495 83	654 52	507 19
			Wt Gas (lbs)	1 8281	6 5625	1875	*	
M	7 x 47	67 lbs	Gal	750	2000	605	750	620
			Cu Ft.	100 27	267 40	80 89	100 27	82 89
			Liters	2838 75	7570 00	2289 92	2838 75	2346 70
			Wt Gas (lbs)	9 25	32 00	875		
G	8 x 48	112 lbs	Gal	1150	3200	1100	1150	1126
			Cu Ft	153 75	427 84	147 07	153 75	150 54
			Liters	4352 75	12112 00	4163 50	4352 75	4261 91
			Wt Gas (lbs)	15 5	50 0	2 0		*
H or K	9 x 48	112 lbs	Gal	1825		1210		1240
			Cu Ft	244 00		161 77		165 78
			Liters	6908 98		4579 85		4693 40
			Wt Gas (lbs)	20 25		25		

Weights v ry depend ng upon p entage of mixtu
Cycl nd rs A B D E M G and H hav med c l valv
Cycl d K h s t nda d val e

of the physical characteristics of these gases cylinder pressures and color markings Table 5 lists the contents dimensions and weights of cylinders in which they are marketed

A satisfactory supply and reserve of gases used in inhalation therapy is of extreme importance Once therapy has begun in

CHAPTER IX

METHODS OF TREATMENT

DRUGS such as thyroxine, thiourea, thiouracil have been employed in an attempt to enable the patient to withstand the ravaging effects of oxygen depletion. None of these has seemed sufficiently specific. An increased tolerance for low oxygen tension, however, has been demonstrated in animals treated with adrenal extracts or ACTH (251). Thorn *et al.* (375) state that it has been demonstrated that 160 milligrams of ACTH daily administered in divided doses over a period of two to five days produces an increase in simulated altitude tolerance of 2000 to 3000 feet above previous basal levels. The future role of ACTH in this condition has not as yet been determined.

Agents such as cytochrome C have been employed to encourage oxygen uptake by tissue. It has been shown that narcotics depress tissue dehydrogenases and not the cytochrome systems. The use of cytochrome C in depressed states has not been proven to be of real value.

Inhalation therapy remains the most important of the methods for the treatment of patients suffering from oxygen deficiency.

A. GAS SUPPLY

Oxygen, carbon dioxide, helium and combinations of these gases are marketed in various sized cylinders. Table 4 lists some

TABLE 4

Physical characteristic of gases

Chemical Symbol	O_2	CO_2	He	CO_2—O_2	He—O_2
Physical State in Cylinder	Gas	Liquid	Gas	Gas	Gas
Full Cylinder—Approx. Press. (psi)	2200	875	1650	2050	1650
Color Marking of Cylinder	Green	Gray	Brown	Gray and Green	Brown and Green
Molecular Weight	32.00	44.01	4.00		
Specific Gravity Gas (Air = 1)	1.105	1.529	0.138		

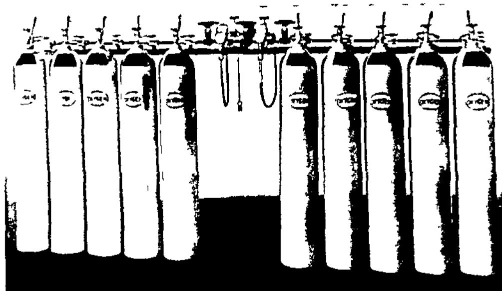


Figure 26 Bank of oxygen cylinders within the hospital

For continued inhalation therapy larger sources of supply are needed The most common in use is the K cylinder K cylinders have either a standard (commercial) or medical coupling to accept regulators These couplings are of different dimensions It is thus wise to standardize on a single type for a particular institution

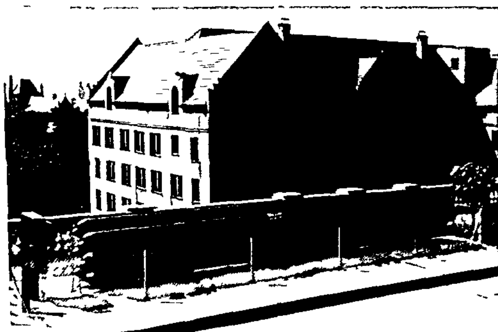


Figure 27 Bank of oxygen cylinders outside the hospital (Cascade system)

terruption because of failure of supply, may be hazardous Patients who have become accustomed to high oxygen atmospheres should not be precipitously deprived of this atmosphere To do so may result in serious injury for the circulatory response may be harmful The patient being relieved of obstruction by helium oxygen if suddenly deprived of this agent, may lapse into a state more serious than that originally present One should have some idea of the effective duration of treatment at given flows from the cylinders employed Table 6 lists the approximate duration of delivery at different flows from cylinders full and partly full

1 OXYGEN

Oxygen used in industry is the same as so called medical oxygen and is less costly The source of supply in the hospital should depend upon how the gas is to be used and what the over all need is Compressed gas in the larger cylinders is cheaper per cubic foot than in the smaller The savings however are tempered by the conditions under which the gases are to be used and the amount needed

TABLE 6

Approximate remaining hours of service at various flows of oxygen for H or K cylinders

Rate of Flow in Liters Per Minute	*Full Cylinder*	*Contents at Diminishing Gauge Pressure*		
	[illegible]00 lbs 6900 liters	*1500 lbs 4560 liters*	*1000 lbs 3100 liters*	*500 lbs 1550 liters*
2	57 hours	38 hours	25 hours	12 hours
4	28 hours	19 hours	12 hours	6 hours
6	19 hours	12 hours	8 hours	4 hours
8	14 hours	9 hours	6 hours	3 hours
10	11 hours	7 hours	5 hours	2 hours
12	9 hours	6 hours	4 hours	2 hours
14	8 hours	5 hours	3 hours	1 hour
16	7 hours	4 hours	3 hours	1 hour

Example Full H cylinder at 2[illegible]00 lbs pressure flowing at rate of 6 liters should last approximately 19 hours A cylinder with 1000 lbs pressure flowing at rate of 8 liters per minute should last six hours

Cylinder sizes A and B are too small except for very brief periods of inhalation therapy D cylinders are of value in transporting patients from the operating room to the recovery room or to the patient s bed

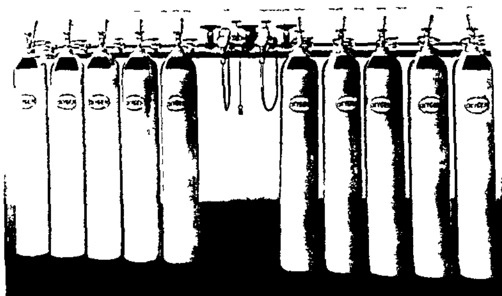


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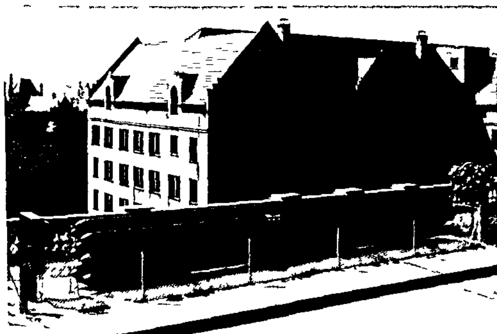


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Approximate remaining hours of service at various flows of oxygen for H or K cylinders

Rate of Flow in Liters Per Minute	*Full Cylinder*	*Contents at Diminishing Gauge Pressure*		
	2200 lbs 6900 liters	*1500 lbs 4560 liters*	*1000 lbs 3100 liters*	*500 lbs 1550 liters*
2	57 hours	38 hours	25 hours	12 hours
4	28 hours	19 hours	12 hours	6 hours
6	19 hours	12 hours	8 hours	4 hours
8	14 hours	9 hours	6 hours	3 hours
10	11 hours	7 hours	5 hours	2 hours
12	9 hours	6 hours	4 hours	2 hours
14	8 hours	5 hours	3 hours	1 hour
16	7 hours	4 hours	3 hours	1 hour

Example Full H cylinder at 2200 lbs pressure flowing at rate of 6 liters should last approximately 19 hours A cylinder with 1000 lbs pressure flowing at rate of 8 liters per minute should last six hours

Cylinder sizes A and B are too small except for very brief periods of inhalation therapy D cylinders are of value in transporting patients from the operating room to the recovery room or to the patient s bed

located in the room wherein the bank is kept, but it would be wise also to place such a bell or red light in the engineer's office It is possible also to connect an alarm system to the hospital's telephone switchboard This makes doubly certain that the signal will be recorded and the proper individual advised to correct the situation

2 CARBON DIOXIDE

The actual use of carbon dioxide in therapy should be very limited Carbon dioxide comes in cylinders of 100 per cent for use in laboratories In this and other high concentrations the gas is

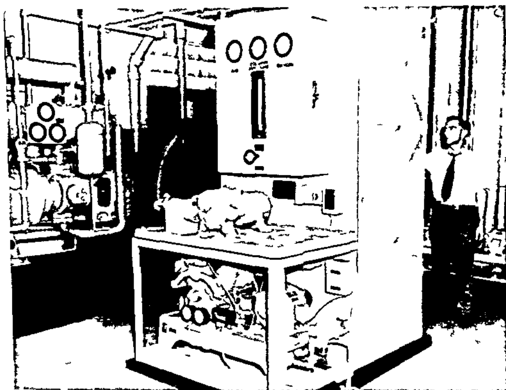


Figure 29 Oxygen plant (courtesy of Air Products Inc)

irrespirable and hazardous Carbon dioxide when used for inhalation therapy should be given with great caution It is administered only for the development of hypercapnea It is best given with room air instead of oxygen so that there will be left in the alveoli no highly absorbable gas as noted in the section dealing with the treatment of atelectasis

The most common way to utilize this gas is from cylinders of carbon dioxide oxygen mixtures They come in various percentages The most common mixtures of oxygen and carbon dioxide

When single cylinders are employed there should always be a stand by in reserve

A central supply of oxygen is very valuable and may be kept within or without the hospital building The line pressure is reduced at the source and the gas is piped through the building to the patient s bedside If the central supply is kept within the building certain precautionary measures such as ventilation should be maintained because of the fire hazard

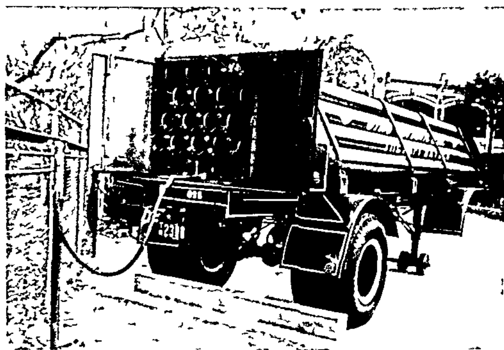


Figure 28 Bank of oxygen cylinders delivered by trailer truck

The central supply may be a bank of K cylinders attached to a common manifold (Figure 26) If outside the building a larger bank of cylinders may be satisfactorily employed (Figure 27) These cylinders are refilled directly by truck A very satisfactory source may be a bank of cylinders loaded on trailer trucks which are hooked up to the hospital system (Figure 28) Some institutions which use very large amounts of oxygen have installed plants for its manufacture (Figure 29)

When banks are employed it is important that there be installed an automatic system to warn when the bank contents become low Such a warning signal in the nature of a bell or red light may be

4 Full and empty cylinders should be kept separately

5 They should be kept in an area free from tampering

6 Never lubricate oxygen valves regulators gauges or fittings with oil or other combustible substances Do not handle oxygen cylinders with oily hands or gloves

7 Never use large cylinders without reducing the pressure through suitable regulator valves intended for this purpose

8 Separate regulators should be used for different gases Regulators used for helium oxygen should not be used on oxygen cylinders

9 Valve protection caps should be kept in place until cylinder is ready for use and replaced after use

10 If a valve is difficult to open point the valve opening away from you and use both hands to give greater force Avoid the use of a wrench or hand wheels and never hammer the valve wheel in attempting to open the valve When valves are encountered that cannot be opened in this way the cylinders should be tagged and returned to the supplier as a safety precaution

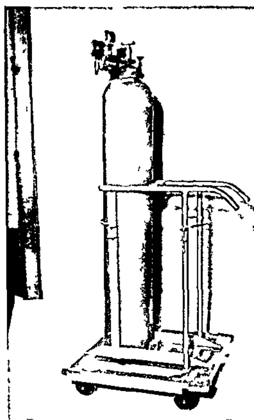


Figure 30 A four wheeled truck for the transport of oxygen cylinders

11 After removing the valve protection cap and before attaching the regulator slightly open the valve an instant to clear out any accumulated dust

12 After attaching the regulator for service and before the cylinder valve is opened be sure that the liter flow adjusting mechanism is in the off position

13 It is most important never to permit oxygen to enter a regulator suddenly Open the cylinder valve very slowly

14 Before removing the regulator from the cylinder close the

are 90–10 93–7 and 95–5 per cent respectively It is best not to attempt to make one s own mixtures of carbon dioxide oxygen

3 HELIUM

Helium is inert It must therefore be administered with oxygen The most common mixture sold is 80 per cent helium and 20 per cent oxygen, but other mixtures can be bought It is best purchased in K cylinders These cylinders of helium oxygen have the so called medical ' thread Thus the reducing valves should be designed to accept this cylinder or one should have available a special adapter If greater oxygen percentages are desired added oxygen may be administered by means of a Y tube

Because of the high cost of helium it is most economically administered in an absorption system wherein carbon dioxide is absorbed chemically It must be remembered that frequent changing of the exhausted soda lime or baralyme used for the absorption of carbon dioxide is necessary Employing an absorption system, one should always be on the lookout for signs of carbon dioxide accumulation Under whatever system helium oxygen is administered carbon dioxide accumulation may be especially disastrous for the patients for whom helium oxygen is employed are usually already dyspneic To further increase the disturbed respiration of dyspneic individuals may aggravate the pathologic condition which is already present

B GAS STORAGE AND HANDLING

Because gases are compressed and are in heavy cylinders and since oxygen supports combustion the use and handling of such cylinders should be surrounded by safety regulations The following is taken in large part from Banash (19)

1 Cylinders of compressed gas should be stored in dry and well ventilated spaces They should be kept upright and in an area through which there is no traffic

2 Cylinders should be stored away from highly combustible materials as oil grease gasoline matches alcohol ether ethylene cyclopropane combustible rubbish etc

3 They should not be stored where they may be subject to excessive temperatures such as heating equipment steam pipes, radiators autoclaves or laundry apparatus

needle valve (Figure 32) may be used Patients may be transported with the cylinder and valve attached to the litter and oxygen delivered by nasal catheter (Figure 32) These simple valves make it possible to administer oxygen in emergencies



Figure 32 A needle valve controlling flow of oxygen transnasally while patient is being transported

1 REGULATOR GAUGES

When gases are administered from large cylinders it is necessary that the gases be reduced to safe pressures When employed in the patient s room a pressure reduction mechanism and a delivery control valve are incorporated in a single apparatus In piping systems the tank pressure is reduced at the bank (Figure 33) and the reduced pressure is delivered to the wall in the patient s room A control valve with flowmeter is needed there (Figures 34 and 35)

Regulators may be of one two or three stages In a single stage valve the pressure is reduced from tank pressure to a working pressure of 60 pounds in a single step (Figure 36) A flow control

cylinder valve and release the pressure from the regulator

15 Never attempt to mix gases in an oxygen cylinder or any other cylinder

16 Do not transfill empty cylinders

17 Use cylinder only when its content is clearly marked

18 Cylinders must not be dropped or allowed to strike each other violently and under no circumstances must a cylinder ever be used as a roller or support

19 When moving large cylinders from storage to point of use or return they should always be transported on a suitable truck and fastened in place on such trucks A four wheeled truck is preferred (Figure 30)

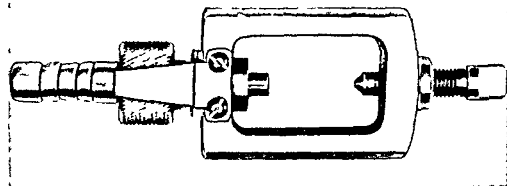


Figure 31 A sleeve valve

20 Cylinders should be securely set at a suitable place at the bedside and either left on the truck, strapped to the bedstead or placed in a corner where they will not be knocked over When it is necessary to have the cylinder somewhat remote from the bed the tubing should be kept high and in sight to avoid tripping or having objects placed on it which might restrict the flow of oxygen to the patient

C GAS DELIVERY

Gas delivery should be controlled as to pressure and flow In using small cylinders for short periods of time one may need no more than a single control valve A reducing valve though valuable is not here needed In its stead a sleeve valve (Figure 31) or a

needle valve (Figure 32) may be used Patients may be transported with the cylinder and valve attached to the litter and oxygen delivered by nasal catheter (Figure 32) These simple valves make it possible to administer oxygen in emergencies



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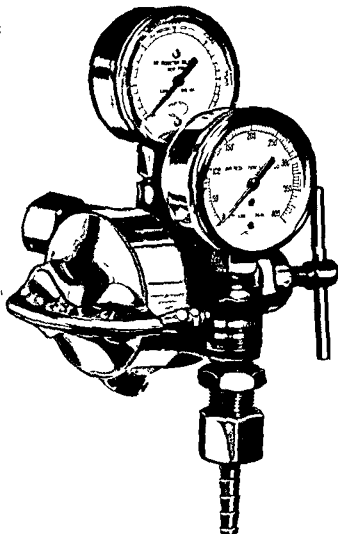


Figure 33 Two stage manifold for use only at banks Two are employed one on each side of the bank As soon as the cylinder pressure in one bank drops the other automatically opens up

valve meters the gas delivery In a two stage regulator (Figure 37) tank pressures are reduced to 400 pounds in one stage and then to 60 pounds in the second stage A cutaway view of a two stage gauge is shown in Figure 38 The flow control governs the rate of delivery from the reduced pressure side of the gauge A three stage regulator (Figures 39 and 40) reduces the pressure to 750 pounds 400 pounds and then to 60 pounds before the gas is metered



Figure 34 Wall box installation with jet humidifier and with needle valve control

It is difficult to distinguish readily between one and two stage regulators One stage regulators are usually thinner in lateral view It is important that one know what sort of regulator he is dealing with for there are hazards and disadvantages to single stage regulators If a single stage regulator with the valve open is attached to a cylinder of oxygen and the oxygen cylinder rapidly opened the gauge may shatter Further, as pressures within the cylinder of oxygen drop the delivery from a single stage regulator is not constant and requires frequent adjustment for uniform delivery In multiple stage regulators the flow is uniform until the cylinder of oxygen is almost exhausted (Figure 41)

Regulators may have either of two sizes of female connections to fit a cylinder the standard to fit commercial cylinders and the medical to fit medical cylinders The standard has a thread size of 906 inches and the medical of 838 inches Cylinders of helium oxygen mixtures have medical threads When using standard thread regulators on medical cylinders it is necessary to employ a special adapter (Figure 42) Thus if one is equipped with standard sized regulators and a helium oxygen mixture is desired it is important that such an adapter be at hand

Regulator valves require care In institutions where they are used in large numbers spare parts and diaphragms or washers should be kept available

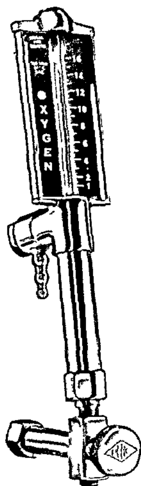


Figure 35 Room outlet kinetic flowmeter and needle valve

2 FLOWMETERS

There are several varieties of flowmeters—the Bourdon (spring type) (Figure 37) the Thorpe tube type (variable orifice float gauge) (Figure 39) and a kinetic type (Figure 36) The Bourdon type is accurate between three to seven liters per minute Error above and below these flows may be up to 10 per cent The Thorpe tube type of flowmeter is said to be accurate at any reading as is the kinetic type The Bourdon tube type is the more adaptable to various forms of therapy however and should be purchased where any of the air injector types of therapy are to be employed The Thorpe tube type of flowmeter has a float or ball which moves up or down to indicate the flow rate The tube is calibrated on the basis of an unobstructed flow of oxygen leaving the flowmeter When the outward flow is obstructed by some attachment such as an oxygen concentration meter back pressure builds up and the reading is altered accordingly It must be remembered that the patient will be receiving more not less oxygen than is indicated on the meter under these circumstances Humidifiers and nebulizers may also impose sufficient back pressure to cause some deviation in the reading

These forms of meters may be incorporated with the regulator or may be attached to wall outlets (Figures 34 and 35) Plug in type outlets may be utilized These have a male and female member (Figure 13) These plug in type adapters also cannot be employed where air injector types of therapy are to be used

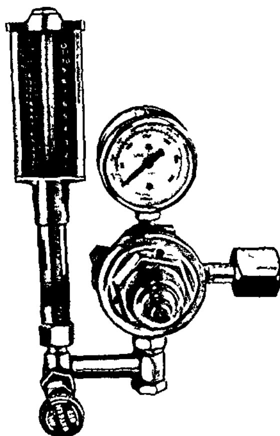


Figure 36 Single stage regulator kinetic type

On occasion regulators become inaccurate and it is advisable at frequent intervals to test the regulators for their accuracy of flow A tester apparatus is very valuable particularly in large installations

When using 80–20 mixtures of helium oxygen through meters calibrated for oxygen the flow actually delivered and the reading on the meter will not correspond because of the difference in

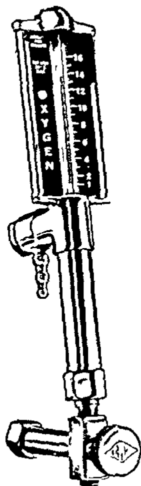


Figure 35 Room outlet kinetic flow meter and needle valve

Regulator valves require care In institutions where they are used in large numbers spare parts and diaphragms or washers should be kept available

2 FLOWMETERS

There are several varieties of flowmeters—the Bourdon (spring type) (Figure 37) the Thorpe tube type (variable orifice float gauge) (Figure 39) and a kinetic type (Figure 36) The Bourdon type is accurate between three to seven liters per minute Error above and below these flows may be up to 10 per cent The Thorpe tube type of flowmeter is said to be accurate at any reading as is the kinetic type The Bourdon tube type is the more adaptable to various forms of therapy however and should be purchased where any of the air injector types of therapy are to be employed The Thorpe tube type of flowmeter has a float or ball which moves up or down to indicate the flow rate The tube is calibrated on the basis of an unobstructed flow of oxygen leaving the flowmeter When the outward flow is obstructed by some attachment such as an oxygen concentration meter back pressure builds up and the reading is altered accordingly It must be remembered that the patient will be receiving more not less oxygen than is indicated on the meter under these circumstances Humidifiers and nebulizers may also impose sufficient back pressure to cause some deviation in the reading

tents hoods cylinders etc used in oxygen therapy should be conspicuously labeled Danger—No Flame—No Sparks" Oxygen regulators should also be conspicuously marked Do Not Oil" All material such as tents and hoods should be of non inflammable material No smoking should be tolerated in the room Neither

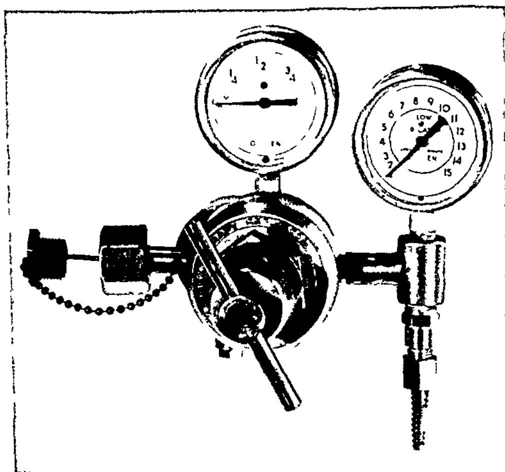


Figure 37 Two stage regulator Bourdon type

electric heating pads nor electric call bells should be used in an oxygen tent Electric motors or other electrical devices should not be employed in the same room

E METHODS

The following are the various types of apparatus which are employed for the treatment of hypoxia or other conditions wherein the patient does not need accessory means to maintain ventilation

densities between the 80–20 mixtures and oxygen. A conversion table (Table 7) is necessary.

TABLE 7

Corrected flow for helium-oxygen mixtures (80–20) when using flowmeters calibrated for oxygen

Readings in Liters per Minute on Flowmeter Calibrated for Pure Oxygen	*Actual Delivery in Liters per Minute to the Patient of*
	He 80% and O_2 20%
1 liter	1.85
2 liters	3.70
3 liters	5.55
4 liters	7.40
5 liters	9.25
6 liters	11.10
7 liters	12.95
8 liters	14.80
9 liters	16.65
10 liters	18.50

3 HUMIDIFIERS

For nasal catheter use especially it is wise that the gases be humidified. Gases may be humidified by various means. Most commonly the gases are bubbled through water. More thorough humidification can be accomplished through a "jet" type apparatus (Figure 34). It is to be noted that this type of humidifier cannot be employed when injector type therapy is employed.

It is often found desirable to employ a space humidifier for use in oxygen tents, bassinets, etc. One developed by Smith and Denton (Figure 44) at the Children's Hospital in Boston is very satisfactory. Humidification of the air breathed by patients with indwelling endotracheal or tracheotomy tubes is frequently necessary. A device (Figure 45) developed by Briggs (77) at the Massachusetts General Hospital does this very well.

D FIRE HAZARDS

The fire hazard associated with oxygen therapy is great. Though oxygen itself is not inflammable, it supports combustion. In the presence of high oxygen concentrations smouldering matches light up, cigarettes become aflame, and an ordinarily insignificant spark on bed clothes may start a conflagration. All equipment such as

tents hoods cylinders etc used in oxygen therapy should be conspicuously labeled Danger—No Flame—No Sparks" Oxygen regulators should also be conspicuously marked "Do Not Oil" All material such as tents and hoods should be of non inflammable material No smoking should be tolerated in the room Neither

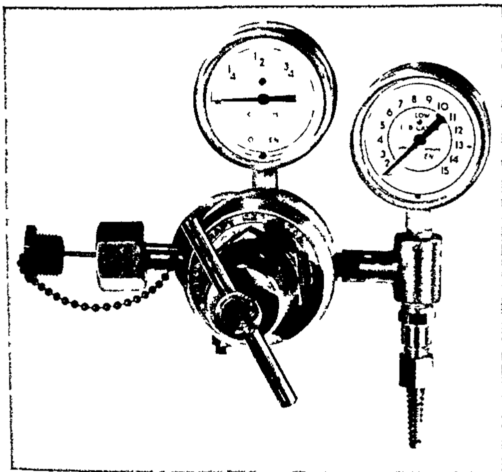


Figure 37 Two stage regulator Bourdon type

electric heating pads nor electric call bells should be used in an oxygen tent Electric motors or other electrical devices should not be employed in the same room

E METHODS

The following are the various types of apparatus which are employed for the treatment of hypoxia or other conditions wherein the patient does not need accessory means to maintain ventilation

1 OROPHARYNGEAL INSUFFLATION OF OXYGEN

With care and proper placement into the oropharynx a nasal catheter is the most satisfactory and economical way to administer oxygen The two most important causes of failure with this method are improper placement of the catheter and leakage

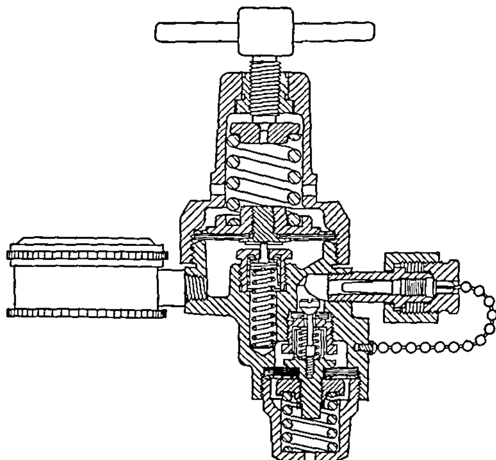


Figure 38 Cutaway view of two stage regulator Bourdon type

a Apparatus necessary are a reducing valve with flow gauge humidifying bottle spare washers 36 inches of thick walled tubing glass connecting tube and several catheters

The type of catheter employed is very important It should have several small openings at the tip to prevent too great dehydration of a small area of mucous membrane Plastic expendable catheters are inexpensive and serve well These catheters should be distinctive in type and color and should be employed for no other pur

pose On occasion, the flow of oxygen has been inadvertently attached to a gastric suction tube with disastrous results Stomachs have been distended and have been perforated by this means Green-colored catheters marked 'For Oxygen Only' should therefore be employed

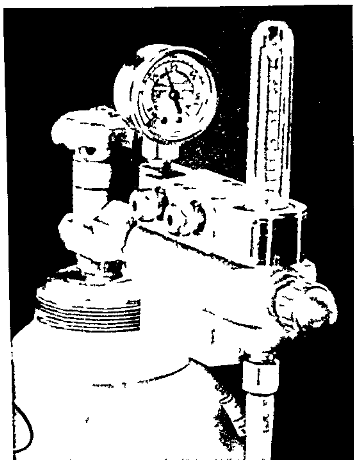


Figure 39 Three stage regulator Thorpe tube type

Humidification of the delivered oxygen is important since a constant stream of oxygen directed at mucous membranes has a great dehydrating effect Washers wear out quickly and others should be available for replacement The tubing should be long enough to allow considerable slack and should be thick enough to be not easily compressible The glass connectors should have large openings at either end for adapters with one end constricted are not satisfactory The catheters should be sizes French 10–12

b Placement of the Catheter

It should be lubricated with a water soluble jelly Liquid petro latum or petrolatum jelly should not be employed since they are not absorbed, and if blown into the lungs may result in lipoid pneumonitis After lubrication the catheter should be advanced

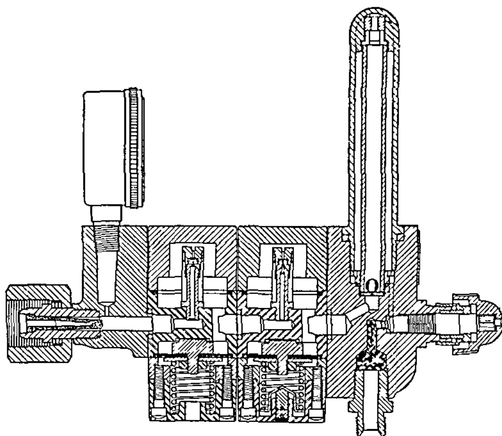


Figure 40 Cutaway view of three stage regulator Thorpe tube type

along the floor of the nose with oxygen running at about four liters per minute until the patient attempts to swallow the de livered oxygen It is then pulled back one fourth inch Its end should rest directly below the tip of the uvula (Figure 16) If the catheter lies too deep in the oropharynx large quantities of oxygen may stream into the stomach or be swallowed and result in gastric dilation

In the cooperative or unconscious individual the tip of the catheter may be inspected by direct vision to ensure accurate

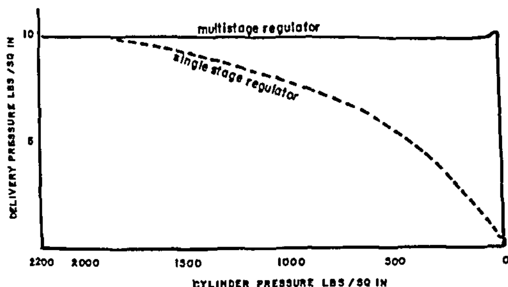


Figure 41 Regulator characteristics comparison flow of multi stage versus single stage regulators

placement (Figure 47) A usually safe guide is to lay the catheter along the patient s face with the tip of the catheter at the tragus of the ear The distance from the tragus of the ear to the external nares minus one half inch is marked off with a narrow strip of adhesive and the catheter is inserted to this point The catheter should be fixed to the skin to prevent displacement and should be so placed that it is not uncomfortable and does not interfere with the patient s vision Adhesive one half inch wide is given a full turn about the catheter and then fixed to the upper lip (Figure 48) This process is repeated two inches further up the catheter and

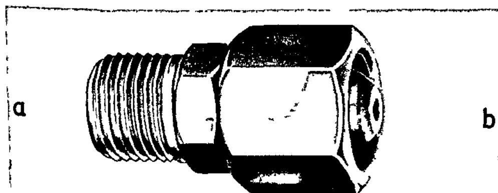


Figure 42 Adapter standard end (a) commercial end (b)

b Placement of the Catheter

It should be lubricated with a water soluble jelly Liquid petrolatum or petrolatum jelly should not be employed since they are not absorbed and if blown into the lungs may result in lipoid pneumonitis After lubrication the catheter should be advanced

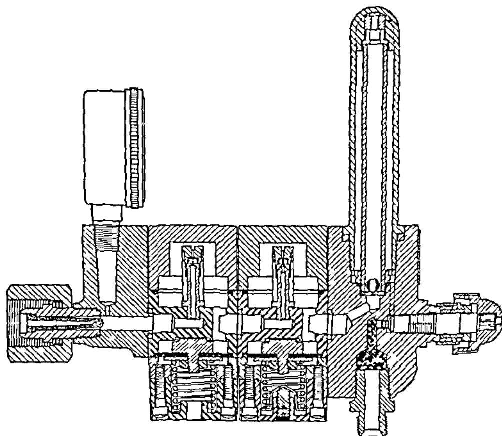


Figure 40 Cutaway view of three stage regulator Thorpe tube type

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In the cooperative or unconscious individual the tip of the catheter may be inspected by direct vision to ensure accurate

TABLE 8

Gas analysis of samples taken from bronchus with delivery catheter properly placed in oropharynx (From Rotenstine, F A, Taylor, I B, and Lemmer, K E Oropharyngeal Insufflation of Oxygen Gas Tensions in the Bronchus, Anesthesia and Analgesia, *Jan–Feb, 1936*)

1 At Height of Inspiration

Oxygen cc per min	*Maximum*		*Average*		*Minimum*		*No of Analyses*
	O_2	CO_2	O_2	CO_2	O_2	CO_2	
None	18 1%	2 7%	17 8%	2 2%	17 5%	1 7%	2
2000–2500	30 4	1 9	29 8	1 9	29 5	2 0	3
4000–4500	43 6	1 8	36 3	1 8	33 2	1 6	7
6000–6500	58 8	1 4	54 8	1 8	50 6	1 4	18
8000–8500	76 7	2 1	66 0	1 5	65 4	1 4	10
10 000–10 500			78 4	1 8			

2 At Height of Expiration

2000–2500	33 7%	5 1%	30 9%	4 1%	28 1%	3 5%	3
4000–4500	38 1	4 6	35 1	4 0	32 1	3 4	3
6000–6500	56 3	3 9	55 4	5 1	54 0	5 8	6
8000–8500			74 8	4 7			1

found almost always to be due to a poor fitting gasket Millions of cubic feet of oxygen have been wasted in therapy and this is the most common way Waste would not be so important did it not mean inadequate therapy

TABLE 9

Oxygen content capacity and percentage saturation of blood breathing air or oxygen at seven liters per minute oropharyngeal insufflation (From Christensen, E M Urry A G and Cullen, S C Alveolar and Arterial Oxygen Contents During Oropharyngeal Oxygen Therapy, Anesthesiology, *7 399–404, July, 1946*)

Patient	*Oxygen Content Vol %*		*Oxygen Capacity Vol %*		*Oxygen Saturation %*	
	Air	*Oxygen 7 liters/min*	*Air*	*Oxygen 7 liters/min*	*Air*	*Oxygen 7 liters/min*
C S	16 13	17 25	17 22	17 22	93 0	100 0
J W	15 50	17 04	17 53	18 11	88 0	93 9
S G	15 81	18 56	18 06	18 02	87 5	103 0
Average	15 81	17 62	17 60	17 78	89 5	99 0

fixed to the skin of the cheek The tubing attached to the humidifier should then be fixed to the head of the bed with sufficient slack so that the patient can turn from side to side without feeling a pull on the tubing (Figure 39) The pillow is usually a poor place to attach this as frequent readjustment of the pillow for the patient s comfort may be necessary

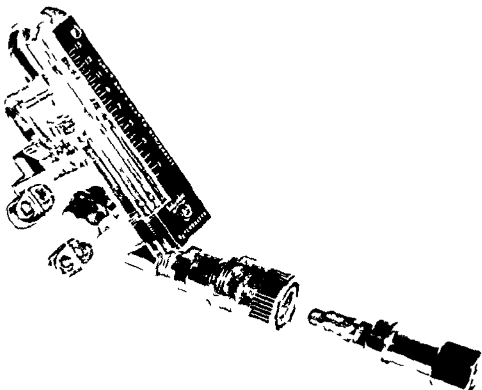


Figure 43 Quick coupling outlet

The most common cause for failure with this type of therapy is leakage around the gasket in the humidifying bottle This cannot be emphasized too strongly Adequate care of the apparatus during its administration requires constant checking for leakage The easiest way to check for leakage is to momentarily pinch off the tube which is carrying the oxygen from the humidifying bottle to the patient Upon sudden release of the tube there should be an audible gush of oxygen down the tube because of accumulated back pressure If this gush is not definitely audible then one must conclude that there is a leak in the system and this leak can be

vanced far enough into the oropharynx satisfactory percentages are not obtained by the quoted deliveries

2 MASKS

Inhalation therapy by face mask has been increasingly employed during the last few years The method has one important advantage—a high oxygen concentration can be delivered very

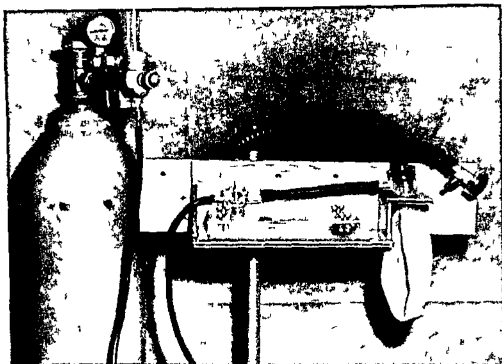


Figure 45 Humidifier for patients breathing through tracheotomy or endotracheal tubes The metal nipple close to the expiratory valve at the extreme right of the apparatus is attached to the tube By this means a humidified atmosphere of a high oxygen tension is breathed Because of directional valves there is no carbon dioxide rebreathing (Courtesy of Dr Bernard D Briggs Massachusetts General Hospital Boston Mass)

promptly after initiating therapy There are, however, a few disadvantages to therapy by this means For treatment to be efficient the mask should fit snugly There should be no leaks for if there are the desired oxygen atmosphere may not be obtained Good fit is not always possible particularly in edentulous patients The patient may be either non-cooperative or restless and will dislodge the mask Mask therapy should be reserved therefore for patients

Adequate care also means frequent changing of the catheters The catheters become encrusted, the nose becomes sore It is suggested that the catheters be changed at least every twelve hours from one nostril to the other The nostril should be kept clean and the removed catheter should be carefully cleansed sterilized and put away for its next use



Figure 44 Space humidifier for use in confined areas as head hoods tents incubators (Courtesy of Dr Robert M Smith Children s Hospital Boston Mass)

A study of Table 8 from Rovenstine *et al* (320) reveals the therapeutic value of oxygen at different flows into an oropharyngeal catheter The effect on the arterial oxygen determination of oropharyngeal oxygen delivery is shown by the work of Christensen *et al* (93) (Table 9)

Inhalation therapy by the oropharyngeal catheter is most satisfactory in adults Most children do not tolerate it well In adults the rate of flow should be from 5 to 6 liters per minute in children it should be reduced accordingly If the catheter is not ad

(1) Semi closed A form of partial rebreathing is the apparatus employed in the semi closed method of anesthesia The method has been employed for oxygen therapy Here the bag is usually large The relief valve opens when the pressure is great enough to overcome spring tension or to elevate a metal disc Because of



Figure 48 Proper fixation of catheter to upper lip and side of face

the hazard of carbon dioxide accumulation this method has very little merit except in emergencies

(2) **B L B** Mask This apparatus (Figures 50 and 51) is a method of administering oxygen wherein partial rebreathing is limited because of a relatively small rebreathing bag Excess gases leave the system through sponge rubber discs located on each side of the equipment If the oxygen delivery is inadequate or if the patient s tidal exchange is greater than the bag contents room air is sucked into the system through these sponge rubber discs The resistance offered by these discs places a burden on already taxed respiratory and circulatory systems Because of the ever present carbon dioxide accumulation the apparatus should not be employed on individ

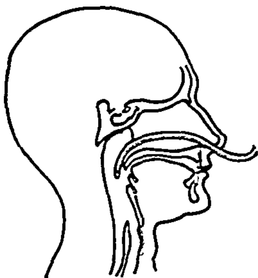


Figure 46 Drawing showing tip of catheter properly placed just below the uvula for insufflation of oxygen into the pharynx.

in whom a good mask fit can be obtained and who will not dislodge the mask

An extremely important consideration in therapy by mask is carbon dioxide accumulation The mask may represent from 50 to 100 cubic centimeters of dead space This relatively small amount by itself may cause sufficient carbon dioxide accumulation to become evident in the patient s condition For this reason particularly mask therapy is contraindicated in children *or in individuals with a small* tidal exchange

The hazard of carbon dioxide excess increases when mask therapy is employed under those conditions where portions of the exhaled mixture are rebreathed

a. Partial Rebreathing

Under this method part of the patient s exhalation enters a bag to be rebreathed The greater the percentage of the expired air rebreathed the greater is the concentration of carbon dioxide in the inhaled atmosphere Several factors govern the amount of rebreathed atmosphere 1) The rate of delivery of oxygen The greater the amount of oxygen delivered the less are gases rebreathed 2) The size of the bag The greater the bag the more likely is carbon dioxide accumulation 3) The amount of pressure within the system necessary to force part of its contents out of the system through a relief mechanism

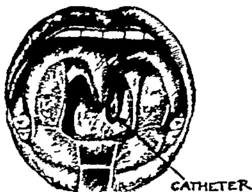


Figure 47 View of tip of catheter just below uvula

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uals with depressed respiration or on children Rates of flow as low as two to four liters per minute will be accompanied by sufficient rebreathing to result in a concentration of carbon dioxide in the inspired air on the order of two to three per cent Because of this it is advisable to employ a flow of at least six to ten liters per minute

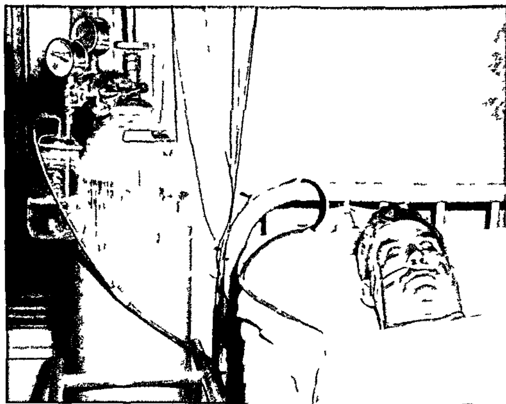


Figure 49 Proper fixation of tubing to head of bed rather than to pillow

When this mask is employed for dyspneic individuals especially those with increased minute volume exchange high flows are indicated to prevent collapse of the bag during inspiration The respiration of a dyspneic individual may be further compromised by forcing him to obtain part of his tidal volume through the sponge rubber discs (366)

b No Rebreathing

Because of the fact that carbon dioxide accumulation is inadvisable in individuals requiring inhalation therapy, apparatus has

been devised to obviate this hazard A very early if not the first piece of equipment designed for this purpose is the Davies Gilchrist apparatus described by Campbell and Poulton (86) With this the patient breathes 100 per cent oxygen and rebreathing is prevented by a one way valve Some of the forms of apparatus currently employed for inhalation therapy without rebreathing are described below

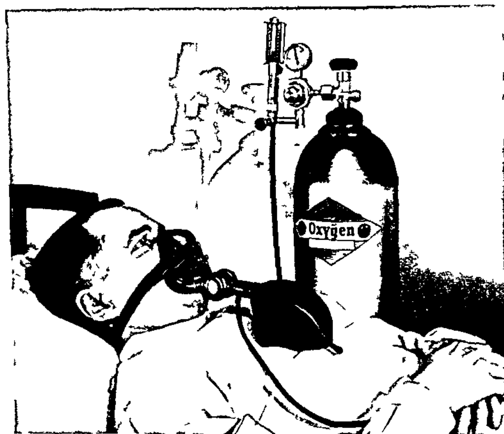


Figure 50 B L B mask (Boothby Lovelace and Bulbulian)

(1) The O E M Meter Mask (Figure 52) To prevent the exhaled gas from being rebreathed (Figure 51) a one way inspiratory valve is located between the collecting bag and the face mask If the bag contents are not *sufficiently great the negative pressure built up* within the mask during inspiration opens the air inlet valve This valve is possibly not great enough in diameter to prevent a too long sustained negative pressure in the pulmonary tree in dyspneic individuals Exhalation is through a valve at the mask In order to

deliver into the bag a sufficient volume of atmosphere to attempt to satisfy tidal requirements an injector valve is incorporated at the reducing valve (Figure 52) By manipulating a disc with varying sized apertures one may control the amount of room air which is mixed with the oxygen stream to give any desired percentage from forty to one hundred When this apparatus is used with a

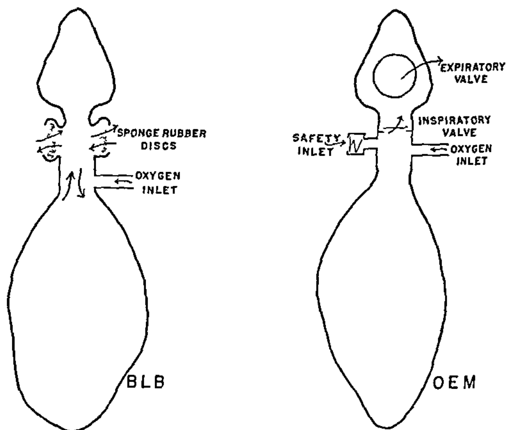


Figure 51 Drawing comparing B L B and O E M (Oxygen Equipment Manufacturing Company) masks

flowmeter which cannot deliver more than 12 liters per minute it may be difficult if not impossible to obtain the higher percentages in patients with increased ventilation

Barach s reintroduction of the injector into inhalation therapy was a great contribution This apparatus is so designed that the gas flowing from the reducing valve is led into a chamber through a narrow orifice A (Figure 53) As it leaves this orifice a negative pressure is created so that air is sucked in through opening B The

oxygen air mixture leaves the chamber at C The volume of air which is aspirated depends upon the size of the port in the metal disc which overlies the apparatus at port B With the largest port over the opening (40 per cent marking) and a 3 liter flow of oxygen



Figure 52 O E M mask Air injector mechanism below reducing valve

per minute 5 liters of air are taken in At a flow of 6 liters per minute 10 liters of air are aspirated This increased volume 8 liters in the former and 16 liters in the latter is of great value in satisfying the patient s tidal requirements Since large volumes can be delivered by means of the injector principle it is of ad

vantage also in situations where it is necessary to wash out carbon dioxide from confined areas This principle should be extended for use in oxygen tents incubators and oxygen rooms

A very similar apparatus is the Resp Aid mask It has advantages similar to those mentioned above

Both the O E M and the Resp Aid apparatus are far more suited to therapy than is the B L B mask The flow of oxygen and

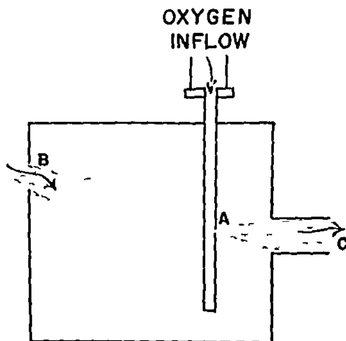


Figure 53 Mechanism of the air injector valve

the amount of air injected should always be at least that necessary to prevent collapse of the bag at the termination of the inspiratory effort The dial over the injector valve should be set at the oxygen percentage desired and the flow of oxygen from the cylinder in creased to a rate sufficient to keep the bag rather full

An important caution is needed It is possible in reassembling the apparatus to reverse the position of the valve between the mask and bag In this position the bag does not fill and tidal require ments are not met properly

A disadvantage in the use of the above mentioned masks is that when the injector valve is employed a humidifying chamber must be dispensed with Patients on whom the above apparatus is em

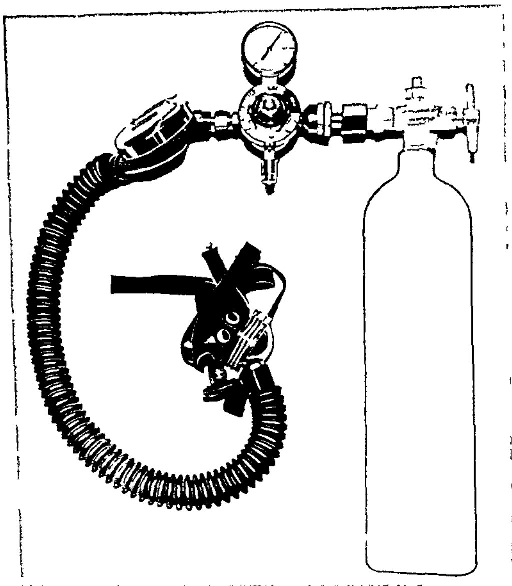


Figure 54 Scott mask

ployed for long periods of time frequently show the dehydrating effect of the dry oxygen on the mucous membranes of the upper respiratory tract

(2) The Scott Mask (Figure 54) This apparatus is of the demand type in which oxygen is delivered to the mask through a wide bore tube No bag for collection of oxygen or rebreathing is employed Upon the creation of a slight degree of negative pressure within the system by the initiation of inspiration, an in

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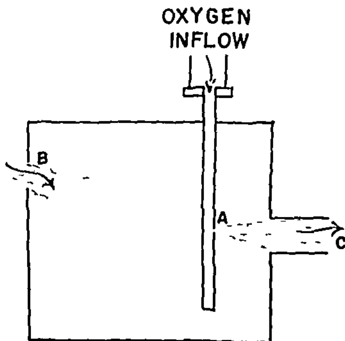


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grades may cause obstruction to respiration A canister of the agent employed may be placed between the mask and collecting bag This apparatus is known as a to and fro apparatus (Figure 55) Chemical absorption may be employed in circuit types of ap paratus, in which exhaled gases are channeled by means of direc tional valves through the chemical absorbent

Utilization of absorption systems should be greater when econ omy of operation is important This may be especially true in the use of helium oxygen mixtures Relatively small flows of oxygen are required once the air within the system and the patient s lungs

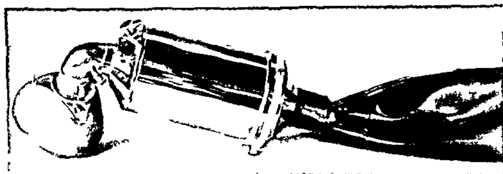


Figure 55 To and Fro absorption apparatus

are washed out of nitrogen Very high oxygen concentrations can be obtained It must be noted that chemical absorption of carbon dioxide by the above agents is not complete As much as 0 5 per cent carbon dioxide may accumulate in the bag This, however compares favorably with the 2 to 3 per cent which may accumulate in the B L B apparatus

The soda lime canister should be renewed every two hours The canister removed should be allowed to rest for a period of hours It can then be re used to a total of not more than five to six hours per pound A pound of baralyme may be used continuously for not more than five to six hours

Oxygen should be delivered at a rate of 4 to 6 liters per min ute for about 10 minutes and it may then be dropped to 1 to 2 liters per minute In tight fitting systems even at this low flow 80 to 90 per cent oxygen mixtures may be obtained

An advantage of absorption systems is the high humidification

stantaneous flow of oxygen is delivered to the mask The creation of a negative pressure of 0 65 millimeter of mercury produces a mass flow of 10 liters per minute A negative pressure of 0 84 millimeter of mercury results in a flow of 40 liters per minute With the creation of a negative pressure of 1 58 millimeters of mercury there results a mass flow of 80 liters per minute The flow can even be greater with increased negative pressures Because of this nearly all instantaneous flow requirements can be met The necessity however, for the creation of negative pressures may be harmful in the presence of obstructive dyspnea pulmonary edema and like conditions An auxiliary flow control creates a slight positive pressure in the system and the creation of a negative pressure is not necessary then to open the demand valve The manual control feature of the auxiliary flow mechanism requires the cooperation of the patient or the presence of an attendant Expired gases leave through a satisfactory exhalation valve

A demand type apparatus should be employed when very high oxygen concentrations are required provided the patient is not dyspneic Such apparatus can deliver higher percentages more satisfactorily than can any previously mentioned mask type apparatus Here too a note of caution is needed Because of the danger of oxygen poisoning this type of equipment should be employed only for such periods as are absolutely required It is not recommended that the Scott mask be used over long periods of time also because of the constant need for some degree of negative pressure to initiate the gas stream Here too the apparatus is not employed with a humidifying chamber and the patient should be watched for dehydration of the mucous membranes of the pharynx and upper respiratory tree

c Absorption

Oxygen can be given by mask in the use of which the exhaled carbon dioxide is chemically absorbed Chemical absorbents for this purpose are employed widely in anesthesia The agents most commonly utilized for this purpose are soda lime and baralyme When soda lime is used it should be of four to eight mesh Finer

negative pressure within the pulmonary tree, and this will tend to produce pulmonary edema

2) Pressure during the *expiratory* phase of respiration

(a) *Method of Plesch* An early apparatus was devised by J Plesch for the treatment of pulmonary edema This apparatus

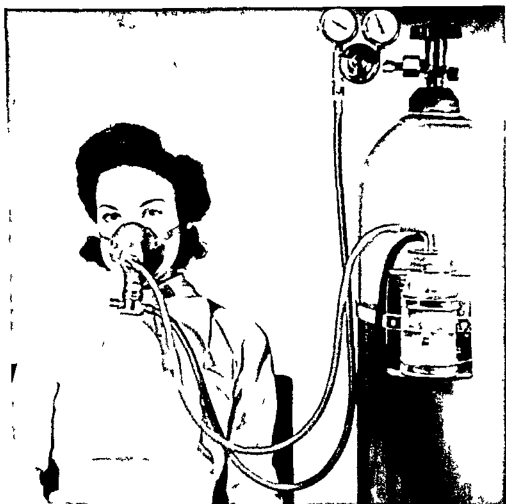


Figure 56 O E M positive pressure mask Pressure is created during expiratory phase by exhaling against the resistance of a column of water

consisted of a mask fitted with a water manometer and an expiratory valve exerting a pressure that can be varied for altering the tension of a spring Through another opening in the mask a motor blower delivers more than enough air for respiration The tension exerted by the spring on the expiratory valve is usually

of the breathed atmosphere A disadvantage may be the increased temperature of the breathed atmosphere because of the chemical interaction between carbon dioxide and the absorbent

d Positive Pressure

The intrapulmonary pressure may be increased for resuscitation purposes or for the treatment of disease Such increase in intra pulmonary pressure may be produced during any of the phases of respiration or throughout the entire respiratory cycle At present there is no general agreement as to the phase of the respiratory cycle in which such an increase should be effected It does seem clear, however that an increased intrapulmonary pressure exerts a direct opposing force on the pulmonary capillaries and will counteract to some degree the elevated hydrostatic pressure present within the capillaries in pulmonary disease, notably in pulmonary edema

Such increased pressure further serves to retard the entrance of blood into the right heart with a consequent reduction of blood in the lung An increased intrapulmonary pressure may be of value in maintaining a greater patency of the tracheobronchial tree

1) Increased pressure during the *inspiratory* cycle Increase of the intrapulmonary pressure during this phase of respiration alone is primarily employed in resuscitation endeavors by means of such apparatus as the Pneumatic Balance Resuscitator and will be considered under the section on Resuscitation Increased pressure during the inspiratory phase however may be of value in some medical conditions such as obstructive dyspnea Bickerman *et al* (65) determined that In the control of obstructive dyspnea due to laryngeal obstruction or to asthma pressure during inspiration provided either by continuous or inspiratory pressure breathing was clinically more valuable than expiratory pressure breathing alone

It must be remembered however that such apparatus as the Pneumatic Balance Resuscitator may not have the high flow rate which may be required at any moment by the dyspneic individual If the apparatus cannot deliver instantaneously the volume required by the patient there will be a short period of heightened

ment of pulmonary or circulatory disease is of itself a real advantage

Barach extended the use of the O E M meter mask apparatus to accomplish the desired purpose by much the same means as did Campbell and Poulton (Figure 56) The exhaled gas from the expiratory valve is guided by means of a tube below the surface of water Here too the length of tubing below the surface of the water controls the amount of resistance to overcome by exhalation thus increasing intrapulmonary pressure

(c) *O E M Positive Pressure Mask* Increase in pressure within the pulmonary tree by this apparatus is developed by requiring the patient to exhale through a choked orifice (Figure 57) A disc with varied orifices is placed above the expiratory valve With the largest port over the communication from the expiratory valve there is minimal resistance As smaller ports are rotated into place over the opening above the expiratory valve one may theoretically obtain pressures of one centimeter two centimeters three centimeters or four centimeters of water One should not always place full dependence upon the fact that pressures will be built up within the mask to correspond with the reading over the port Factors which prevent such pressure from being developed are leakage about the face mask inadequate flow of oxygen and a small tidal exchange

Motley *et al* (282) report a case where the O E M apparatus above described employing 100 per cent oxygen and three centimeters of water expiratory pressure failed to overcome pulmonary edema Use of the Pneumatic Balance Resuscitator however cleared the edema

(d) *Anesthesia Machines* A few of the modern machines employed for anesthesia have a very well calibrated relief valve Weights of varying size may be placed over the spill valve These machines employ absorption methods for the removal of carbon dioxide With a tight fitting mask and a flow of oxygen sufficiently great to raise the required weight during expiration increased intrapulmonary pressures can be developed accurately

3) Pressure throughout the *entire* respiratory cycle (Continuous Positive Pressure Breathing) Increased positive pressure through the entire respiratory cycle can be accomplished on some models

set so that expiration can only take place at a pressure of 30 centimeters of water

(b) *Method of Campbell and Poulton* (86) These authors describe a simple apparatus It consists of a face mask with two respiratory openings one connected with a motor blower and the other with a tube that can be lowered beneath water in a tall bottle Excess of air is supplied to the mask from the blower and



Figure 57 O E M positive pressure mask Pressure is created during expiratory phase by exhaling through a choked orifice overlying the mask

bubbles off beneath the water so that the patient breathes under a positive pressure which can be regulated by altering the depth of the tube beneath the water The possibility that an insufficient volume of air to satisfy tidal needs may be supplied by the above means may be a real objection to the development of intrapulmonary pressure by the use of air administered by motor blower

The use of compressed oxygen for this purpose is more frequently employed today for the added use of oxygen in the treat

be sufficient not only to overcome the benefits which might be obtained from the increased intrapulmonary pressure, but even to increase the underlying pulmonary edema

One cannot leave a consideration of methods of increasing intra pulmonary pressures without noting that such increases may have a deleterious effect on circulation The hazards of increased pres sure during the inspiratory versus the expiratory phase or through the entire respiratory cycle are to be considered in the section on Resuscitation Added to the effects of increased pressure on cir culation is the known hazard of carbon dioxide retention, par ticularly when pressures are maintained during the complete cycle

Because of the circulatory effects of positive pressure therapy one should administer it very cautiously in the presence of shock wherein the venous return to the heart is retarded If peripheral circulatory failure is suspected or present positive pressure ther apy should be employed only with careful attention to the blood pressure Should a fall of blood pressure greater than 10 millime ters of mercury occur, this form of treatment should be discon tinued

When employing positive pressure therapy in the presence of pulmonary edema one should begin with a pressure of about 5 centimeters of water pressure, and then gradually lower it to one centimeter of water One should hesitate to use a pressure higher than 4 to 6 centimeters of water pressure for anything except brief periods for the higher the pressure employed the greater will be the effect on circulation

3 HEAD HOODS

a Burgess Box

(1) Burgess Open Box Burgess *et al* (81) first described this apparatus in 1932 Continued study was made by them (82 83) The principle of use of this apparatus is based upon the fact that if oxygen which is heavier than air is introduced into a container which is closed on all sides except the top it will accumulate and high percentages can be obtained Experimentally oxygen was ad mitted three inches from the bottom on opposite sides of an open container Samples taken showed increasing concentrations as one

of the Connell gas machine. The relief valve is set for the maximum pressure which is considered safe for the individual and by a unique arrangement, varying weights are placed upon the rebreathing bag. The tidal exchange may be determined on a calibrated strip.

Another apparatus (Figure 58) is designed to administer positive pressure on either inspiration or expiration, independently or together. Pressure of 2 to 12 centimeters of water may be obtained.

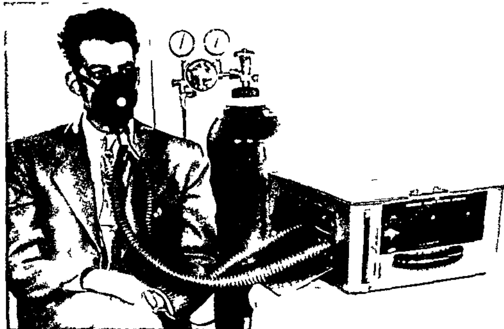


Figure 58. Continuous positive pressure breathing apparatus.

These pressures are produced by weights on individual bellows for inspiration and expiration. Carbon dioxide accumulation can be prevented only by large delivery flows of the gases. An injector meter is incorporated at the delivery gauge when using oxygen so that various concentrations may be obtained. The injector meter is by-passed when using helium-oxygen mixtures.

Whichever apparatus is employed, it is necessary that the flow of gases into the bag should be of such volume that the collecting bag does not collapse near the termination of inspiration. Were it to collapse when using the O.E.M. apparatus, the heightened negative pressure developed to open the emergency air intake would

children When used for infants and small children the neck piece can be snugly fitted about the abdomen

In using this apparatus as in the use of oxygen tents, frequent oxygen determinations should be made Leaks are thus readily determined Leaks can be very much better controlled in this type of apparatus than in the large oxygen tents

At low flows carbon dioxide may accumulate to as much as 2 or 3 per cent Because of this Burgess incorporated a soda lime container into the apparatus Since currents of air were not actively directed through the soda lime carbon dioxide absorption remained inefficient With children flows of 1 to 5 liters and with adults of 6 to 7 liters per minute are required to keep the carbon dioxide concentration at low levels

It is important to keep the ice container nearly full at all times for efficient operation depends upon down currents of oxygen mixed with air

A very great advantage of this apparatus over the oxygen tents is that the chest and abdomen of adults receiving therapy by this means may be exposed for examination A drinking tube may be inserted through a sleeve like arrangement A nurse may reach over the top of the tent to feed or care for the patient s facial needs

An apparatus similar in appearance to the above is sold by the O E M Corporation The Ohio Chemical and Mfg Co markets a similar product under the name Oxylator Inspection of commercial products said to serve as does the Burgess Box has revealed that they are not entirely satisfactory It has been found difficult to maintain satisfactory concentrations in some of these The great mistake which has been made is that of not adequately covering the ice chamber In one model the ice chamber is not covered and as a consequence downdrafts are created and room air is sucked in

As above mentioned these hoods seem to be of especial value to infants who require oxygen Carbon dioxide accumulation is especially hazardous to children particularly those who are running a fever A very satisfactory way to administer oxygen to these patients in this hood is to use an injector valve By increasing the volume which enters the box the carbon dioxide content can be kept at a minimum

approached the bottom of the container At a flow of 4 liters per minute concentrations of 50 per cent and higher were obtained at a point six inches above the floor of the box At greater flows greater concentrations could be achieved

One side of the box was replaced with a plastic material with a hole through which the patient s head could be admitted to the



Figure 59 Burgess Box

box A sleeve like arrangement fitting snugly about the neck prevented leakage Two sides were replaced with clear plastic material To prevent excess humidity and to allow for cooling a covered ice chamber was placed within the box near the top and oxygen was delivered into it The cooled air carrying with it the oxygen is carried downward by currents The circulation thus created maintains comfortable conditions within the box The inside of the box can be kept below room temperature and humidity The frame was then dispensed with and the entire apparatus except the ice box was made of plastic material which was suspended from an overhead frame (Figure 59)

We have found this apparatus to be of very great value Patients tolerate it very well It is especially suited for infants and young

It must be re emphasized that denitrogenization by the use of 100 per cent oxygen should not replace intestinal intubation for the treatment of paralytic ileus It should be employed in addition to this latter means Results to be obtained from the use of the method alone however, are occasionally spectacular

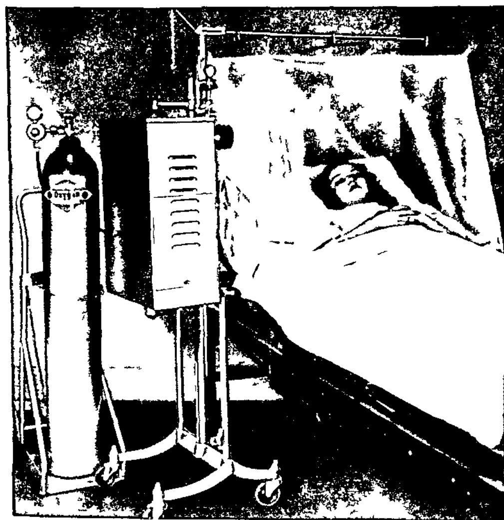


Figure 60 Oxygen tent ice cooled

4 TENTS

Large canopies can be placed about the patient in attempts to confine increased oxygen concentration In so doing it is essential that means are incorporated for efficient oxygen delivery, cooling and dehumidification

Oxygen delivery must be rapid to reach a desired concentration

Denton (118) adapted a Burgess Box for infants Instead of having the opening tied around the youngster s abdomen, he put the infant entirely within the Burgess Box and drew the drawstring tight and placed the entire apparatus inside the baby s crib By closing off the drawstring entirely, he was able to improve the percentage of oxygen in the apparatus Where a 6 liter flow originally yielded a mixture of 32 to 38 per cent oxygen closing off the opening elevated the concentrations to 62 to 72 per cent oxygen The use of the box in this fashion is of advantage, since the infant can be easily cared for He can be kept in the tent during feedings nursing care and physical examination

(2) **Burgess Closed Box** Following the work of Fine *et al* (156) as previously mentioned in the section on Denitrogenization it was evident that high concentrations of oxygen had considerable merit for this purpose Burgess (80) described an adaptation of his open box method By placing a cover over the open box it was possible by large flows of oxygen to achieve a concentration of 95 per cent A spill valve need not be employed for it is better to have the oxygen leak outwards wherever leaks may develop

The tightly closed container increases the possibility of carbon dioxide accumulation Saklad and Burgess (323) employed the principle of chemical absorption of carbon dioxide An injector valve was placed at the reducing valve The tubing carrying the oxygen was admitted to the usual position on the Burgess Box Gases were sucked back into the injector through a cylinder of soda lime This circulation carried the carbon dioxide into the chamber where it was absorbed The carbon dioxide free atmosphere was then re circulated into the closed box The negative pressure created by the above mentioned injector valve at various flows of oxygen was sufficient to guarantee free circulation

The patient is placed in the apparatus with even more than ordinary care to prevent leaks A flow of 12 liters per minute is started and maintained until the desired concentration is obtained The oxygen delivery may then be reduced to 6 to 8 liters per minute Careful and frequent oxygen determination should be made

Barach (33) described the use of an injector meter based on the above principle for enclosed head hoods

tion of the inhaled oxygen atmosphere to that of the room A patient in need of oxygen should not be exposed to such acute changes The respiratory and circulatory response to sudden changes are undesirable

Cooling and dehumidification are dependent upon efficient circulation through a cooling chamber Circulation may be produced by a motor blower or by thermal circulation Cooling may be by ice (Figure 60) or by electric refrigeration (Figure 61) An advantage of the use of the tent is the possibility of maintaining cool atmospheres It has been shown experimentally that cooling of the body increases the ability to withstand oxygen lack by decreasing oxygen requirement

An interesting and valuable use of the oxygen tent is in conditions wherein pollen filtration might be of value as in patients suffering from asthma The tent provides a very satisfactory, air conditioned pollen free atmosphere

Tents have distinct disadvantages (34) Since the average adult gives off approximately 250 cubic centimeters of carbon dioxide per minute it is necessary for the amount of oxygen delivered into the tent to be on the order of 25 liters per minute to keep the concentration of carbon dioxide to less than 1 per cent in the inhaled atmosphere Such a delivery of flow cannot be maintained by the average reducing valve on the market and to do so would be wasteful of oxygen

Barach (34) is convinced that a tent that maintains 50 per cent oxygen at a flow of 8 liters per minute is not operating satisfactorily as the carbon dioxide concentration must necessarily be above 1 per cent His argument is sound and all efforts should be made to keep the carbon dioxide concentration down We have in the past been told that the hazard of carbon dioxide accumulation in tents is not great since carbon dioxide is said to diffuse through the rubber walls much more rapidly than does the oxygen or nitrogen that is in the tent Dr Barach s point however is well taken and only emphasizes again that those engaged in oxygen therapy should be constantly aware of the hazard of carbon dioxide accumulation

Oxygen therapy by tents can be of value only if the nursing attendant is aware of the many details necessary to maintain proper temperature and oxygen concentration Since the danger of leak

It is extremely difficult if not sometimes impossible, to maintain satisfactory oxygen tensions because of the great tendency for leakage The flow of oxygen should be maintained at high levels to compensate for such leakage and to wash out carbon dioxide Conservation of the flow of oxygen by utilizing chemical absorption of

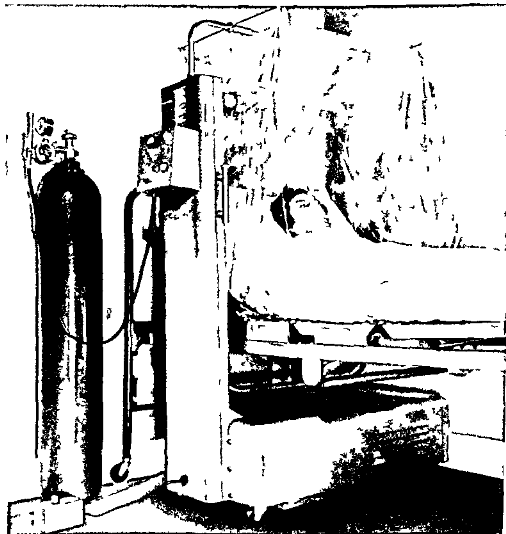


Figure 61 Oxygen tent electrically cooled

carbon dioxide is not satisfactory since low flows will not compensate for oxygen lost by leakage

It is very difficult to maintain satisfactory oxygen tension for adequate periods in the tent Examination feeding or care of the patient s physical needs mean a reduction in the oxygen concentra

tion of the inhaled oxygen atmosphere to that of the room A patient in need of oxygen should not be exposed to such acute changes The respiratory and circulatory response to sudden changes are undesirable

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Oxygen therapy by tents can be of value only if the nursing attendant is aware of the many details necessary to maintain proper temperature and oxygen concentration Since the danger of leak

age is so great no tent should ever be employed without frequent analysis of the oxygen content and a bedside record of such findings kept The plastic material should be closely tucked in under the mattress The tent should not be opened except for necessary care of the patient Should it be required at any time to enter the tent or to remove the patient one should first shut off the motor to conserve what oxygen there is in the refrigerating chamber When the patient is returned to the tent the motor is turned on again and oxygen at 15 liters per minute administered for 20 minutes This is followed by a maintenance flow of 10 to 12 liters per minute and will give approximately a 50 per cent mixture in the tent

5 OXYGEN CHAMBERS

a Oxygen Rooms

An oxygen room is by far the most comfortable means of oxygen administration from the patient s viewpoint This method is especially valuable if oxygen therapy is necessary or desirable over long periods of time Although many newer methods have particular indications for specific conditions this method of therapy should be seriously considered in new hospital construction or in those older institutions where inhalation therapy is properly administered

Barach (22) devised and employed a portable oxygen room which can be installed in a patient s home This form of oxygen room is an expanded oxygen tent with rigid walls The actual need *for such equipment is probably small*

Permanent installation of such rooms have been described (27 28 67) For efficiency and safety several desiderata must be sought The room itself should be airtight so that satisfactory oxygen percentages may be reached and maintained The room should have two well fitting doors with special locking devices for tight closure One door should be wide enough to allow entrance of a bed The second door should be smaller for the use of attending personnel The smaller door should give admission through an air lock or be covered on the inside by a special curtain to prevent dilution of the atmosphere of the chamber The door should have a panic

bolt mechanism for rapid opening from the inside Food and drugs should be passed into the chamber through a small air lock

As a safety precaution the inside of the room should be either not painted, or painted with fireproof material Automatic sprinkler heads should be built into the ceiling The contents of the room should be as nearly fireproof as possible There should be no electrical equipment or outlets of any kind in the room No electrical call bells or switches should be used A call cord through a tight fitting connection may be installed to ring a bell outside the unit No matches cigarettes or cigarette lighters should be allowed in the room and patients and attendants should be instructed as to this The room should be lighted from the outside through glass panels

Oxygen supply should be from outside the chamber preferably from a double bank of cylinders with an automatic valve so arranged that when the pressure within one bank drops to 50 pounds the other bank begins to function Samples for analysis of oxygen and carbon dioxide contents should be taken through a sampling tube in the wall of the room

Temperature control circulation and dehumidification are special problems in such a unit Binger (67) circulates the air by means of a pump outside the room Air is sucked from the room through ducts by a fan and then driven through a cooling and dehumidification unit and then back into the room The shaft of the fan is carried from the wall of the duct system through an airtight stuffing box to the motor

Barach (27) recommends temperature control and dehumidification by means of *thermal circulation On one side of the room is* built a bank of pipes through which brine circulates On the other side of the room is a radiator Adequate circulation is achieved by the cool air dropping and the warm air rising The moisture in the air condenses on the brine pipes and is collected in a catch pan By this means the room can be dehumidified and the temperature kept satisfactory

There remains the problem of carbon dioxide accumulation Binger (67) has incorporated soda lime containers into the duct system Carbon dioxide tension in the room should be kept as low as possible The oxygen delivery into the room should be great

for it has a two fold function (1) To maintain the desired oxygen concentration and (2) to wash out carbon dioxide

Taran and Szilagyi (368) kept children with acute rheumatic carditis in an oxygen room for from 24 hours to 40 weeks with an average of 12 weeks time The oxygen concentration was kept be tween 45 to 50 per cent Twenty four of the 44 children treated showed definite clinical improvement as a result of oxygen therapy Seventeen were not benefited Most of this latter group were ad vanced cardiacs with long standing carditis and evidence of heart failure Three children did not tolerate the therapy well They were all the bronchitic type of rheumatic carditis The oxygen chamber seemed to aggravate their respiratory condition

All the children who showed clinical improvement had a signifi cant fall in temperature This improvement appeared within the first 24 hours in 18 of the 24 patients in this group Twenty of this group showed immediate improvement in respiration with slow ing of rate and relief of dyspnea Twenty two gained weight at a greater rate than a similar group would have outside the chamber Appetite improved in all children who tolerated the chamber as did complexion and behavior

The authors state that although established cardiac damage cannot be reversed by oxygen therapy such therapy reduces sig nificantly the functional cardiac disability associated with acute carditis and favorably affects the clinical symptomatology toward more complete recovery

The same authors studied 15 representative cases of acute rheu matic carditis (369) All of these patients showed a return of the Q T T Q ratio in the direction of normal when oxygen therapy was instituted They believe that improvement in the functional cardiac disability of acute carditis observed in oxygen therapy may prevent further cardiac damage during the acute phase of carditis

b Incubators

For many years it has been customary to place premature infants and the newborn whose general condition is not good in incu bators An example of such an apparatus is shown in Figure 62 In such equipment temperature and humidity control are relatively easy to obtain More recently the endeavor has been to increase the

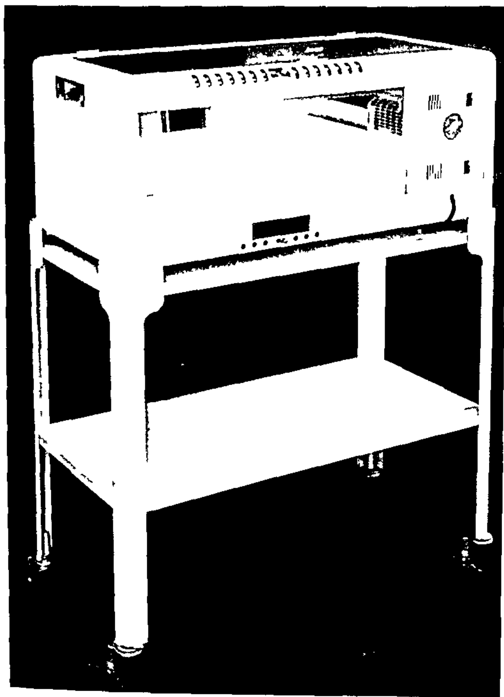


Figure 62 Infant incubator

oxygen percentage within the incubator To do this, manufacturers have found it necessary to make the apparatus more nearly leakproof Because of this feature the generally unrecognized hazard of carbon dioxide accumulation is ever present The manufacturers have recommended insufficient flows of oxygen The oxygen delivery should not only raise the percentage of oxygen within the chamber but should serve also to wash out any carbon dioxide which may have accumulated There is no reason why our experience with other forms of closed systems should not be applied to incubators The adult when exposed to inadequate temperature control deficient oxygen administration or carbon dioxide accumulation may become restless or indeed may fight to get out of the unit The baby cannot protest to the same degree Whenever the youngster is kept in a confined atmosphere the flow of oxygen should be kept at a flow greater than that necessary to give the desired oxygen concentration Here too, one should take advantage of the injector valve to increase the flow of gases into the chamber Oxygen determinations should be made frequently

Most incubators are heated and their humidity is controlled by electricity Some units have motor driven pumps for circulating air through the apparatus One should be positive that the apparatus is free of any fire hazard Before using oxygen in any such equipment one should be certain that all heating elements light bulbs switches wiring etc are properly installed

6 EQUALIZING PRESSURE CHAMBER

Thunberg in 1926 (376), developed a barospirator wherein patients completely enclosed were subjected to an alternating increase in pressure on the order of one sixth of an atmosphere 25 times per minute This increase in pressure is equivalent to the delivery within the lungs of approximately 500 cubic centimeters of air Barach (24) showed that pressures so administered did not maintain a normal arterial oxygen tension and carbon dioxide elimination The resistance offered by the tracheobronchial tree so delayed the transfer of pressure within the chest cage that the external pressure caused the thorax to become compressed (25 30) To obviate this delay an apparatus (Figures 63 and 64) was so built that the pressure applied about the outside of the lower part of the

body was delayed by a baffle plate and by a differential pressure about the head By alteration of the degree of baffling and the differential pressure the chest could be kept stationary and arterial oxygen and carbon dioxide kept within normal range The degree of differential pressure about the head is about 5 millimeters of mercury

As originally designed the apparatus created alternating positive and negative pressure of 55 millimeters of mercury By careful alteration of the degree of baffling these variations in pressure were found to limit chest expansion completely In apparatus now being developed the pressures are alternated from −120 centimeters of water to −2 centimeters of water Here too satisfactory fixation of the chest wall can be obtained In the former apparatus because of the required compression of gases in the positive phase heat is generated within the apparatus Because of this a refrigerating unit is incorporated to keep the temperatures at a comfortable

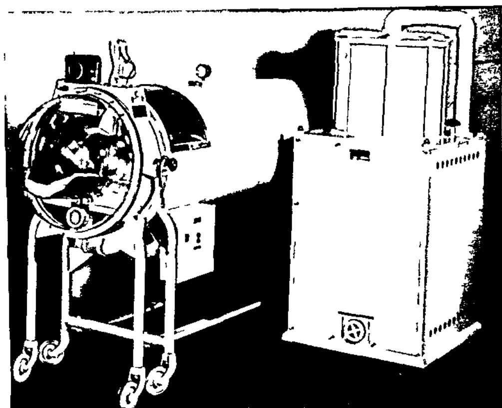
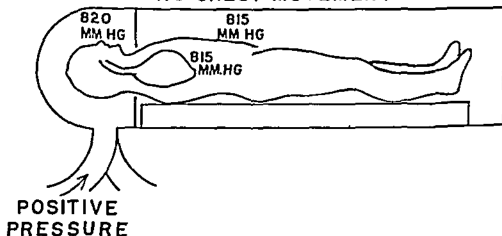


Figure 63 Equalizing pressure chamber (Lung Immobilizer)



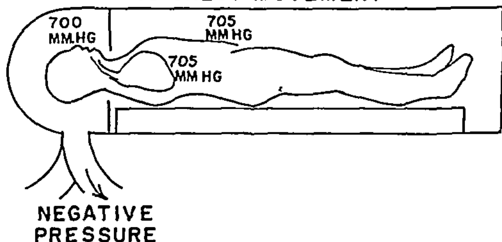


Figure 64 Principle of equalizing chamber

range No refrigeration is required in the apparatus which employs negative pressure only since there is no compression of gases and no heat generation

Resistance offered by the tracheobronchial tree which requires an increase over that ordinarily found necessary in the differential pressure between the head and body portions of the chamber, is found in bronchial asthma pulmonary emphysema and pulmonary fibrosis

During treatment ear discomfort may appear One patient in Barach s series had ear pain and discharge after 10 days of treatment

Since effort in the treatment of pulmonary tuberculosis is in the direction of resting that portion of the lung so involved, Barach reasoned that a good rest may be obtained by use of the equalizing chamber In this apparatus he treated patients who were in advanced states of the disease Within the first and second weeks a drop in temperature and pulse rate appeared Between four to six weeks after treatment was begun there appeared a decrease in cough and expectoration The majority of patients exhibited an increase in weight X ray evidence of improvement was noticed at the end of the second or third month of treatment

Some patients were treated eight to 10 hours a day and some for six full days out of each week with time out of the chamber only for meals and bodily needs The first few times the patient is placed in the chamber he must be coached to allow the apparatus to breathe for him Once he has been accustomed to the machine full physical and psychic relaxation occurs

Barach reports (32) that of 12 cases of advanced bilateral and moderately advanced pulmonary tuberculosis clinical recovery took place in six–marked improvement in one slight to moderate temporary benefit in three and no change in two Eight were given a single course of treatment of three to four months for eight to eleven hours daily Three had two courses and one patient had three courses of such therapy

Since it is possible by differential pressure to maintain the thorax safely in a fixed position this method of treatment would seem to be indicated in several surgical conditions Patients with paradoxical respiration following removal of part of the chest wall or due to injury would seemingly be benefited if similar results could be obtained with them It is hoped that such indications will be considered and investigated

7 EXTRAPULMONARY ROUTES

By its title this book should be limited to a consideration of the lungs as an avenue for the administration of gases Several methods however have been employed to administer oxygen by routes

other than by way of the lungs Oxygen has been injected into body cavities for its local effects, and into the vascular tree for its systemic effects

a Local Effects

Because of edema in localized infections there is interference with blood flow through the part, with a localized Stagnant Hypoxia To relieve this condition, oxygen has been injected into infected areas such as abscess cavities, and into infected joints by Rost (317) Barker (47) treated two cases of gas gangrene by oxygen injection into the infected area with apparently good results Rost also injected oxygen into the peritoneal cavity in the treatment of tuberculous peritonitis This method was employed for the same purpose by Grewal (184) and by Stein (367)

Felsen (151) in the treatment of ulcerative colitis injected oxygen into the rectum at a rate of 125 cubic centimeters per minute until an amount of 2000 cubic centimeters had been administered He thought that the presence of oxygen in the rectum not only inhibited the growth of anaerobic bacteria but made the mucous membrane more capable of resisting infection

Barker (47) also used oxygen injections to improve the oxygen uptake of non infected tissue He recommended intracutaneous injection of oxygen into full thickness skin grafts in which blood supply had not been well maintained He also suggested its use in crush injuries wherein the damaged tissues had oxygen injected into them for the purpose of prolonging their viability Guess (187) employed subcutaneous oxygen in the treatment of certain forms of pruritis ani

The true value of oxygen injected into tissues for its subcutaneous local effect has not been fully determined There may be some justification for hesitating to carry needles into infected areas Injection of oxygen under some of the above conditions may, however be of value

b Systemic Effects

Inhalation therapy may not on occasion be efficacious because the tidal exchange may not be great enough to carry oxygen in sufficient volume to the alveoli or because a barrier has been set

up by the presence of exudate preventing satisfactory transfer of oxygen from the inhaled atmosphere to the blood

Oxygen is poorly absorbed by the gastrointestinal tract The amount that can be taken up from the stomach is probably not more than 30 cubic centimeters per hour (252) McIver *et al* (270) have shown that oxygen is absorbed about four times as rapidly by the mucous membrane of the small intestine as by that of the stomach Such slow rates of absorption cannot be relied upon to be of any therapeutic value

Attempts to inject oxygen subcutaneously and intravenously have been made to satisfy the oxygen needs of the patient in hypoxic states

(1) Subcutaneous Bayeau (51 52) recommended oxygen subcutaneously for mountain climbers and balloonists Wood (401) found it advantageous to have oxygen injected into himself before air trips Welsh (389) employed subcutaneous oxygen for resuscitation purposes in conditions such as asphyxia neonatorum, drowning carbon monoxide poisoning etc He found it of value in the treatment of circulatory failure and shock

Campbell and Poulton (86) calculated that after the subcutaneous injection of 500 cubic centimeters of oxygen the rate of absorption was no greater than 0 18 cubic centimeter per minute Singh (356) believed that oxygen was not absorbed more rapidly than 0 6 to 1 2 cubic centimeters per minute In spite of the limited absorption of oxygen from the tissues this method has been employed by many Among others Simon (352 353) believes he obtained good results by the subcutaneous use of oxygen in clinical practice

Simpson and Barker (355) carried out a series of experiments to determine whether in hypoxic states the uptake is greater than under normal circumstances or whether there are other beneficial effects from the injection of oxygen They concluded that there was no supporting evidence that the uptake of injected oxygen was sufficient to relieve oxygen want in the animal

(2) Intravenous Nysten (288) in 1811 injected oxygen intravenously into dogs He found that moderate sized dogs could tolerate up to 20 cubic centimeters at a time and by allowing three to four minutes between injections he could give a total of 100 to

150 cubic centimeters without harm Above such volumes or if the oxygen were injected more rapidly, gurgling sounds could be heard from the chambers of the heart Bourne and Smith (71) working with dogs found that oxygen given in excess of 0 75 cubic centimeter per kilo per minute produced dyspnea due to embolism Tunnicliffe and Stebbing (380) injected 500 to 1000 cubic centimeters of oxygen per hour with what they felt were good results Singh and Shah (357) noted that the signs and symptoms of pulmonary embolism in man were the same as those in animals Singh and Shah state that in man about 10 to 20 cubic centimeters of oxygen a minute can be administered intravenously this is about 10 per cent of the basal requirement This is the only method by which any considerable amount of oxygen can be administered by an extrapulmonary route This amount of oxygen does not appear to be considerable but still a distinct clinical improvement follows its administration Gaertner (162) in 1902, gave oxygen intravenously to dogs He found that it did not interfere with circulation to the lungs Emboli or bubbles of gas were found in the right ventricle but never in the left heart It was his belief that danger symptoms can be obviated by stopping the injection of oxygen

Ziegler (402) described an apparatus for the intravenous administration of oxygen Cyanotic patients he believes can be relieved by this method with a drop in pulse rate and improvement of the blood pressure On one occasion following the intravenous administration of oxygen a comatose patient become conscious One patient with severe pulmonary edema was entirely relieved after 12 hours following five hours of intravenous administration of oxygen He employed between 200 and 600 cubic centimeters per hour He believes that the presence of bubbling by auscultation over the heart shows oxygen in the right side of the heart but the left side of the heart has no oxygen which means to him that the oxygen is absorbed before it reaches the left side of the heart He feels that the hazard of oxygen embolism is not great because the phenomena of air embolism are produced by nitrogen He gives as contraindications to the use of intravenous administration of oxygen advanced tuberculosis and emphysema because in both conditions there is a marked diminution in the capacity of the vascu

lar bed of the lungs Markow *et al* (267) administered oxygen intravenously in amounts ranging from 3000 to 22 000 cubic centimeters in one, two or three stages in a series of nine cases of severe and persistent bronchial asthma usually after the onset of an attack Oxygen was administered intravenously at the rate of 600 cubic centimeters per hour Following such therapy the vital capacities on all cases were increased from 30 to 87 per cent This increase was maintained in five cases after one month, and in one case after three months In all cases there was some degree of immediate relief of clinical symptoms appearing within five minutes to two hours after the beginning of therapy This was evidenced by a definite lessening of dyspnea wheezing respiration and respiratory effort

Sanders and Isoe (326) attempted to determine the efficacy of oxygen given intravenously to four conscious patients They confirmed the work of Grodins Ivy and others (185) They demonstrated a *fall* in the oxygen saturation of the arterial blood following such administration This fall in saturation was due to gaseous pulmonary embolism for only a very small part of the gas is absorbed into the blood during the passage of the gas through the systemic veins heart and pulmonary arteries Absorption is delayed because only a very small surface of the gas is exposed to the blood column of the vessels The creation of emboli is not without significance particularly since the rate of disappearance of the gas is extremely slow and these bubbles might be large enough to occlude smaller pulmonary arteries or at least occlude the arterioles Their subjects exhibited chest pain cough and restlessness Some perspired profusely and had a slightly increased respiratory rate That a systemic hypoxia occurred is evidenced by the following (1) symptoms of cerebral hypoxia occurred in one patient They consisted of aphasia facial paralysis and clonic contractions of his upper extremities (2) Symptoms of myocardial hypoxia occurred in another patient and consisted of precordial pain (3) Changes in electrocardiographic tracings occurred in the two patients on whom they were taken These changes were in the T waves and the S T segments and are comparable with those occurring in the oxygen deprivation test for angina pectoris

The hypoxemia is due to pulmonary occlusion Pulmonary em

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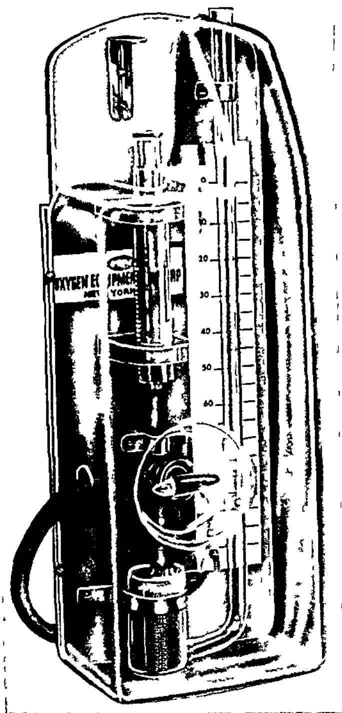


Figure 65 Oxygen analyzer employing chemical ab sorption

bolism may set up a reflex vasospasm and possibly bronchospasm with a further augmentation of the hypoxia The evidence that this reflex spasm occurs is suggested by the following (1) The occurrence of vagal stimulation This might be explained by the lack of the increased pulse rate in spite of the presence of hypoxia (2) That sympathetic stimulation occurs is evidenced by all of the first four patients displaying marked profuse perspiration The amount of oxygen absorbed by the venous blood from the time of its introduction into the vein until its passage to the smaller pulmonary arteries is insignificant Too the gaseous pulmonary embolism causes a decreased pulmonary circulation, arterial hypoxemia and systemic hypoxia In its present status the value of intravenous oxygen as a therapeutic measure is questionable and because of pulmonary embolism the procedure is definitely hazardous

(3) Intra arterial To avoid the possibility of pulmonary embolism, oxygen has been injected intra arterially in the hope that the oxygen may be picked up by the capillaries of the limb An insufficient amount of work has been done on this aspect to warrant any conclusions

F METHODS FOR OXYGEN ANALYSIS

Badger (17) recommended a solution of copper ammonium chloride as a reagent for oxygen analysis This solution consists of equal amounts of water and concentrated ammonium hydroxide (28 per cent) saturated with ammonium chloride in the presence of a copper screen Figure 65 shows an apparatus devised to employ this agent A very simple one and one which may be home made was recommended by Andrews and Roth (10)

There has been introduced recently a method for analyzing ozygen which is very accurate simple and constant Pauling, Wood and Sturdivant (295) devised a simple and effective instrument for determining the partial pressure of oxygen in a gas (Figure 66) It is based on the principle that oxygen is paramagnetic and thus this method can only be accurate in the absence of other paramagnetic gases such as nitric oxide nitrogen dioxide and chlorine dioxide Since these gases are unlikely to be present in an atmosphere in which therapy is administered one could conclude that any reading obtained would be due to the presence of oxygen As the unit

double scale calibrated in millimeters of mercury partial pressure and percentage of oxygen concentration

Attached to the back of the instrument is a glass cylinder con taining silica gel of the indicator type When the hand bulb is squeezed the gas to be sampled is drawn through the silica gel and its moisture removed The gas then passes by diffusion into the analysis chamber The silica gel in the glass cylinder should be blue in color When it turns pink it indicates that the contents of the cylinder must be replaced or removed and dried Reheating will restore the silica gel to its original color and water adsorption efficiency The operation of the meter is simple the technician simply squeezes the hand bulb four or five times to get a true sample of the tent or hood atmosphere then places the instrument on a flat surface presses the button and takes the reading when the light beam comes to rest

The apparatus measures the oxygen partial pressure of the gas sample translating the measurement into percentage of oxygen on the indicating scale The scale is calibrated in both oxygen per centage and oxygen partial pressure The reading is accurate only at sea level since a decrease in pressure causes a decrease in scale reading For example if a reading of 50 per cent is obtained at an altitude of 5 000 feet above sea level the actual percentage of oxy gen in the sample will be 60 per cent A conversion table Table 10 is thus necessary when employing this apparatus at higher alti tudes

TABLE 10

Conversion table for oxygen analyzer (paramagnetic gas principle)

Altitude	*Instrument Reading*	*Actual Percentage*	*Instrument Reading*	*Actual Percentage*
(Sea Level)	20 9	20 9	50 0	50
1 000	20 2	20 9	48 4	50
2 000	19 5	20 9	46 8	50
3 000	18 8	20 9	45 1	50
4 000	18 1	20 9	43 4	50
5 000	17 4	20 9	41 6	50
6 000	16 6	20 9	39 9	50

volume of oxygen being a paramagnetic gas, is increased, its partial pressure is increased causing a proportionately stronger magnetic force To measure the change in this force the oxygen in the chamber diffuses into a unit which has a test body consisting of a small glass dumbbell containing an inert gas The dumbbell and a small reflecting mirror are attached to a silica fiber suspended in a

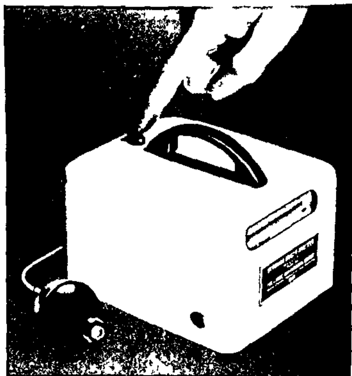


Figure 66 Oxygen analyzer utilizing paramagnetic gas principle

magnetic field The magnetic field is produced by a permanent horseshoe magnet As the partial pressure of the oxygen varies the dumbbell rotates in the inhomogenous magnetic field An electrical unit consisting of two flashlight batteries a flashlight bulb a light beam projector and the switch is enclosed in the back of the instrument Pressure on the button of the instrument closes a circuit which casts a light beam on the mirror attached to the rotating dumbbell This beam which indicates the degree of rotation of the dumbbell assembly is thrown back upon a mirror which in turn reflects it upon the scale on the front of the instrument This is a

essential that entrance of air, air and oxygen, or oxygen alone, which is to get to the lungs be not obstructed This, of course, means the establishment of a satisfactory airway The gas that is sucked in by the creation of a negative intrapulmonary pressure or forced in because of an increase in atmospheric pressure should be in satisfactory volume to supply oxygen requirements The lungs should be satisfactorily emptied so that excess carbon dioxide can be eliminated A near normal tidal exchange is therefore absolutely necessary

The maneuvers and gas pressures employed should not be harmful to the patient Circulation should not be hampered or impeded

In all methods of artificial respiration the attempt is to establish a normal tidal exchange The more nearly normal the tidal exchange the better will be the patient s chances of survival Since many of the methods herein described do not produce an efficient tidal exchange and since the patient s condition may be critical, it is worthwhile if possible to increase the percentage of oxygen in the inhaled atmosphere It is of value to supplement all manual methods of artificial respiration by a flow of 6 to 10 liters of oxygen per minute through a nasal catheter * Apparatus has been devised so that a constant flow of oxygen can be delivered to a mask attached to the patient s face These are inhalators and should not be confused with respirators In the former oxygen is delivered to the mask and the changes in intrapulmonary pressures control the oxygen intake into the pulmonary tree Such pressures depend upon the patient s own efforts or the effects of the manual methods of resuscitation ' Respirators not only deliver the oxygen but also alter intrapulmonary pressure to effect an increased tidal and minute volume respiration

A THE AIRWAY

As stated one of the objectives of artificial respiration is a satisfactory pulmonary exchange This cannot be obtained unless a clear airway is established and maintained

An occlusion to respiration may have been the initiating mechanism for the asphyxial state The obstruction may be due to for

* For proper placement of catheter see page 174

CHAPTER X

RESUSCITATION

I VENTILATORY RESUSCITATION

VENTILATION and circulation are interdependent Failure of one means failure of the other Occasionally both may fail simultaneously Failure of respiration may occur before cardiac cessation The interval between the two is the resuscitative period The duration of this interval depends upon the state of oxygenation of the tissues and blood, and the condition of the cardiovascular system when the respiratory accident occurs If the accident is primarily one of acute deprival of oxygen in an individual with a normal cardiovascular system, resuscitative efforts if started early enough can be expected to result satisfactorily The results cannot be expected to be so good if the patient s cardiovascular mechanism is poor to begin with If the initiating mechanism is cardiac cessation failure of respiration follows very promptly Although an increasing number of lives has been saved by cardiac resuscitation it is hoping for a great deal to expect the results to be uniformly good since the time interval between cardiac cessation and the development of an irreversible state is so short and the endeavor required to correct it so heroic Lay personnel can be taught to ventilate a *person but cardiac resuscitation often requires opening of the* chest and cardiac compression This demands the presence of skilled personnel Further, cardiac arrest preceding cessation of respiration is much less common than is the reverse state of affairs It is safe to say that were all individuals requiring resuscitation treated on the assumption of primary failure of respiration the number saved would be far greater than if dependence were placed on cardiac stimulation alone

Fundamental objectives in artificial respiration are the establishment of an effective oxygenation of the blood and a satisfactory elimination of excess carbon dioxide To obtain these results it is

the patient's head upon its axis will suffice to relieve pharyngeal obstruction. Likewise, relief may be obtained by advancing the lower jaw forward by pressure applied back of the angles of the jaw.

Artificial airways are of great value. Oral airways come in many sizes (Figure 67). Properly placed, one will keep the tongue sepa-

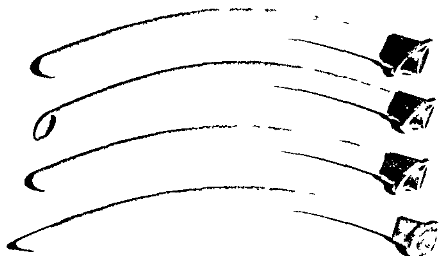


Figure 69 Nasopharyngeal airway of all sizes

rated from the posterior pharyngeal wall (Figure 68). It is often impossible early in cases of hypoxia to open the patient's mouth to insert an oral airway. A nasopharyngeal airway will serve in good stead. These, too, come in various sizes (Figure 69). Inserted into a patient's nostril, one will advance along the floor of the nose into the patient's oropharynx. There it maintains an airway between the tongue and the posterior pharyngeal wall (Figure 70). A simple and effective means of opening the mouth of a semiconscious patient is to place one's index finger in the mouth, slide it between the teeth and cheek to the back of the molar teeth, and then exert downward pressure. The reflex opening of the mouth may be for a very short interval and one should be prepared to insert an oropharyngeal airway immediately. Caution should be exercised

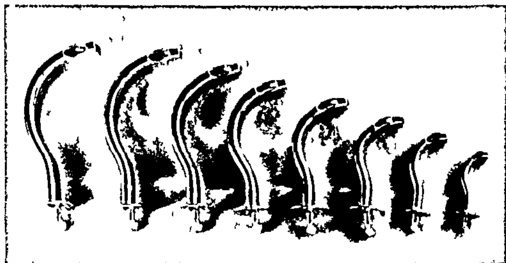


Figure 67 Oral airways of various sizes

eign material or as the result of the mechanism responsible for the acute oxygen deprivation. Regurgitation of gastric contents, masseter spasm or convulsions may cause interference with respiration. Often the respiratory occlusion is due to muscular relaxation with an associated pharyngeal obstruction.

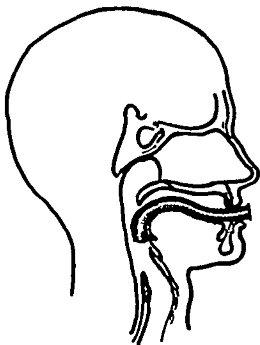


Figure 68 Placement of oral airway

Acute oxygen want may take place under a diversity of conditions and situations and the necessary apparatus for the relief of obstruction may not be at hand. There are several simple means which are very often effective.

The drowned individual or one who is vomiting should be kept on his side with hips elevated to encourage postural drainage. Pharyngeal obstruction can be relieved by traction on the tongue. The tongue can be pulled forward by an instrument such as a pair of pliers or may be kept forward by the fingers. A handkerchief between the fingers and tongue will prevent slippage. Very often simple extension of

be suffering from acute oxygen deprivation in a variety of medical conditions Patients semi-comatose from disease or sedation very often suffer from partial respiratory obstruction because of relaxed pharyngeal musculature Because of this obstruction the tidal exchange is decreased Increased inspiratory effort is an attempt to overcome this obstruction creating a heightened intrapulmonary negative pressure Heightened intrapulmonary negative pressure in the presence of oxygen want may produce pulmonary edema This vicious cycle can be often prevented by the early insertion of an airway oral or nasopharyngeal The presence of an airway in a semi-comatose patient is an index of good medical care Internists in general are not sufficiently aware of the hazard of foreign material in the tracheobronchial tree Cardon (88) states

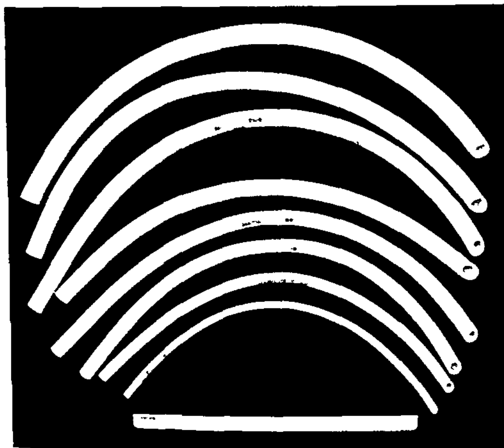


Figure 71 Endotracheal tubes various sizes

1 The onset of tracheal rales should be regarded as a sign not

in preventing one's finger from getting between the patient's teeth and thus being bitten

If the resuscitative effort is carried out where all desired equipment is available an endotracheal tube should be passed They can be obtained in all sizes (Figure 71) Such a tube can be passed either through the mouth (Figure 72) or the nose (Figure 73) It is best to pass the oral endotracheal tube under direct vision For this it is necessary that one have at hand a laryngoscope endotracheal tubes and suction equipment (Figure 74) If one is experienced it is not difficult to pass an endotracheal tube by the nasal route blindly The mask of resuscitating apparatus can be placed on the face over such a tube Compressed air or oxygen can thus be delivered directly to the respiratory tract With this method it is possible that positive pressure respiration may inflate the stomach To prevent this it is often advisable especially if the patient has undigested food or liquids in his stomach to guarantee that the respiratory and gastrointestinal tracts are separated effectively An inflatable cuff about the lower end of the endotracheal tube prevents aspiration about the tube into the trachea (Figure 75) With the cuff inflated and the resuscitating equipment attached to the endotracheal tube (Figures 76 and 77) one need have no fear that the stomach will be distended The presence of an endotracheal tube further ensures that collections of mucus in the tracheobronchial tree can be removed by aspiration

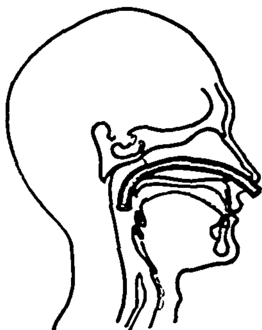


Figure 70 Placement of nasopharyngeal airway

We have too long reserved direct attack upon respiratory obstruction to patients suffering from sudden oxygen deprivation during anesthesia or as the result of accident Patients however can

several tries will fall into the trachea Insertion is aided by changing the position of the patient's head, if the first few trials fail by flexion and then extension A further aid to the passage of the catheter may be traction on the tongue by means of a piece of gauze Constant suction on the catheter is maintained and entrance

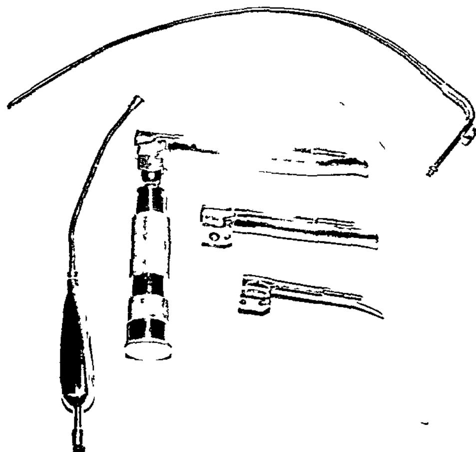


Figure 74 Apparatus for endotracheal intubation Laryngoscope with detachable blades various sizes Endotracheal tube oral suction tip and suction catheter

of the catheter through the glottis will be manifested by the reaction of the patient The patient will cough and may develop some bronchospasm Coughing advances the material in the smaller bronchi into the main stem bronchi wherefrom it is further advanced into the trachea Tracheal aspiration is frequently followed by a marked sense of relief and clinical improvement

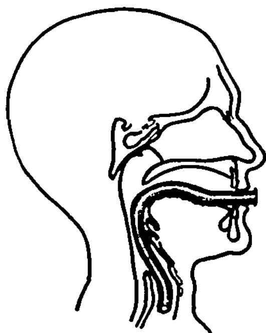


Figure 72 Placement of endotracheal tube oral route

that death is imminent and inevitable but that accumulated tracheobronchial secretions must be aspirated *without delay* 2 The internist or general practitioner must be ready to undertake this life saving measure without depending on the assistance of a specialist 3 Death even in a serious disease may not be caused by the toxicity of the disease itself but by an incidental complication the relief of which may give the patient time to recover Tracheobronchial aspiration is of great value in those conditions wherein the mechanisms which normally keep the air way clear are impaired as in bulbar poliomyelitis tetanus and whooping cough Other conditions in which this procedure is often a valuable adjunct to treatment are cerebrovascular accidents brain tumor acute head trauma meningitis bulbar and pseudobulbar palsy myasthenia gravis alcoholism and diabetic or uremic coma etc

There are several ways of performing tracheobronchial aspiration The simplest is by the use of a urethral catheter All that is required is a catheter of about size 16 French and a suction apparatus The well lubricated catheter can be passed through a nostril and after

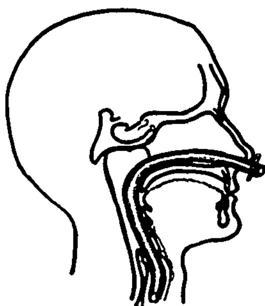


Figure 73 Placement of endotracheal tube nasal route

When animals are asphyxiated to the stage of apnea, resuscitation is accomplished just as quickly by insufflation with pure oxygen as it is with carbon dioxide mixtures, in the presence of profound asphyxia pure oxygen is more efficacious than carbon dioxide Following resuscitation with pure oxygen the restored respiration remains normal in rate amplitude, and general character but following resuscitation with carbon dioxide mixtures the respiration tends to be convulsive and irregular it frequently becomes shallow so that further artificial respiration is needed

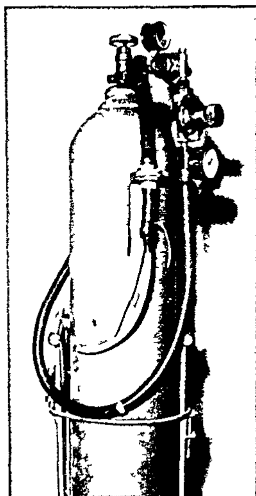


Figure 76 Endotracheal tube attached to P B R apparatus

Grodins *et al* (186) studied acid base changes in the arterial blood in dogs during fatal hypoxia and during successful resuscitation It appears from their studies that it is unnecessary to add carbon dioxide to the resuscitation mixture in order to maintain a normal pCO level during the application of *artificial respiration* and that this is true as long as the lung ventilation does not exceed the average normal minute volume The latter condition is unlikely with most methods of artificial respiration

2 ANALEPTICS

Analeptics have been similarly employed for their respiratory effect An analeptic as defined by Eckenhoff *et al* (139) is a drug capable of stimulating the normal central nervous system and which is used for the purpose of overcoming a depression of

If it is not possible to pass a urethral catheter into the trachea in this fashion it is then wise to intube the trachea under direct vision The patient is carefully laryngoscoped and an endotracheal tube or urethral catheter passed into the trachea If employing an endotracheal tube the urethral catheter can be passed through it It might occasionally be necessary to bronchoscope the patient to clear the tracheobronchial tree This latter procedure however is very seldom necessary Usually the patient by means of cough delivers the contents of the main stem bronchi into the trachea

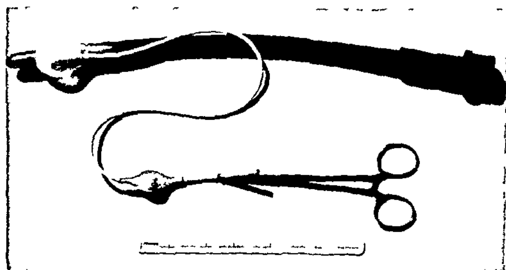


Figure 75 Endotracheal tube with inflated cuff

It must be emphasized that the patient s response to such manipulation is apt to be considerable The bout of laryngospasm or bronchospasm which may ensue is not without danger In spite of this however if the patient s condition is being harmed by even subclinical oxygen want the endeavor to clear the tracheobronchial tree is indicated and should be instituted

B DRUG THERAPY

1 CARBON DIOXIDE

The use of carbon dioxide has been advocated in the treatment of depressed or absent respiration The reader is referred to the section Indications for Carbon Dioxide Eastman *et al* (135) state

are alphalobeline, and irritants such as smelling salts aromatic spirits of ammonia, whiskey and brandy

3 Drugs which stimulate both the central nervous and cardio vascular systems and which in sufficient dosage produce not only convulsions but also hypertension and tachycardia This group includes practically all the aromatic sympathomimetic amines but for this purpose those in which the central nervous stimulant ac tion is relatively great and the sympathomimetic effect relatively small are preferred to those in which the opposite relationship exists Examples of these are amphetamine (benzedrine®) d am phetamine (dexedrine®) and desoxyephedrine (methedrine®) These are preferable to epinephrine paredrine or neosynephrine hydrochloride®, with ephedrine in an intermediate position

4 Substances which exert a specific stimulant effect on nerve tissue by entering directly into the biochemical reactions on which the excitability of this tissue depends These include intermediate products of carbohydrate metabolism such as pyruvate succinate and fumarate as well as the components of the vitamin B complex

The authors state Analeptics have not proved to be infallible when used in the treatment of central nervous system depressions This may mean that the drugs now available for this purpose are deficient in important respects and that intensive search is indi cated for other agents which would produce superior clinical re sults

In evaluating individual analeptics the authors stress that the following facts must be recognized (a) Patients have recovered from more than usually fatal doses of barbiturate without the benefit of an analeptic (b) there are definite hazards in the use of analeptics for the treatment of depressant states and (c) no ana leptic can be depended on to cause the recovery of a patient deeply depressed from a usually fatal dose of barbiturate

Picrotoxin Although picrotoxin is the most potent analeptic agent for use in treating barbiturate depression there is no com pletely convincing proof that this drug is the best analeptic for use against all narcotics Sub-convulsive doses do not affect circula tion or respiration or elicit other signs of significant central nerv ous system stimulation in normal human beings If however picrotoxin is given to an animal in which respiration and circula

that system These authors present a thorough evaluation of such agents They divide these drugs into four categories

1 Those which have a primary stimulant action on the nervous system and whose value depends on that action Drugs which be



Figure 77 Endotracheal tube attached to Emerson suck and blow apparatus

long to this category include picrotoxin metrazol® (pentamethyl enetetrazol) nikethamide (coramine®) strychnine caffeine and atropine

2 Drugs the analeptic effects of which are due to reflexes from one source or another Most powerful of such reflexes are those in the carotid and aortic bodies Examples of drugs in this category

are alphalobeline and irritants such as smelling salts aromatic spirits of ammonia whiskey and brandy

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tion have first been depressed by a barbiturate a response in respiration and a rise in blood pressure may be noted It is important that one appreciate that picrotoxin has a delayed action time as long as 10 to 30 minutes If this latent period is not appreciated, picrotoxin may result in harm because of overdosage Convulsions may be produced leading to secondary depression and even to loss of life

These authors stress that in profound depression picrotoxin should be administered only to the point where reflexes have returned and blood pressure and respiration are maintained The duration of action of a single dose of picrotoxin is longer than that of metrazol® or nikethamide Therefore in its use, the interval between doses should be longest with picrotoxin This agent is apparently not the drug of choice in all depressions Its use would seem to be precluded in any but deep depression caused by the barbiturates It is said to be contraindicated in morphine poisoning

Metrazol® seems to be inferior to picrotoxin in potency Unlike picrotoxin its action is immediate following intravenous injection Like picrotoxin, this agent has very little effect on the respiratory center in the unanesthetized animal Its injection may be followed by a transient hypotension Patients who have received pentothal anesthesia and who have been awakened by intravenously administered metrazol® may retch and vomit upon awakening The action of metrazol® is brief and it has not been uniformly effective against large doses of the longer acting barbiturates

Nikethamide is seemingly not so valuable as either picrotoxin or metrazol® in the treatment of barbiturate depression Its use may be followed by secondary depression without convulsions The authors state In a number of controlled experiments in which nikethamide was used to treat a central depression the incidence of deaths was higher in the treated group than in the controlled group

Strychnine produces its effect principally on the spinal cord and therefore should not be used to combat depressions of the medulla and the higher centers It is said to be inferior to picrotoxin or metrazol® as an analeptic

Sympathomimetic Amines These drugs used alone as analeptics should be reserved until further data are forthcoming They may, however, be profitably combined with metrazol[(R)] or picrotoxin therapy

Miscellaneous Drugs Caffeine is ineffective as an analeptic *per se* When used in large doses in the treatment of narcosis it is inferior to other analeptics and may cause further depression The use of camphor as a stimulant has almost ceased, because of its inefficiency Alphalobeline may exert a decided, but brief, stimulant effect on respiration by way of the carotid body reflex Its effects, however are uncertain and are usually followed by a period of depression due to a nicotinic action Alphalobeline is not to be recommended because of the availability of better analeptic drugs

Succinate, Pyruvate and *Fumarate* The use of these agents is not associated with convulsions The authors state There is no other reason for one's substituting them for other standard analeptic agents at present'

They believe that if the mechanism of action of an analeptic can be accepted as a physiologic antagonism to a depressant drug it follows that the analeptic should only be used when a drug depression exists Anoxia and asphyxia are not indications for the administration of analeptics adequate pulmonary ventilation with 100 per cent oxygen may lead to the reinstitution of respiration under these conditions when analeptics has failed

They conclude, Picrotoxin and metrazol[(R)] are the most valuable analeptics obtainable today, with picrotoxin being the most potent Picrotoxin is also more dangerous to use and should only be used in deep depressions and then by someone well versed in its action and that the use of analeptics in the treatment of depressions should be only a part of a carefully integrated schedule of treatment including oxygen therapy pressor drugs fluid and pulmonary ventilation if necessary as well as more than one analeptic if indicated

Kreiselman (240) and Eastman and Kreiselman (136) believe that alphalobeline metrazol[(R)] picrotoxin and coramine[(R)] have no place in the treatment of apnea at birth because their effect on respiration is nil in the presence of hypoxia

Mousel and Essex (283) have found that not only are these drugs of no value in stimulating respiration and circulation when these centers are depressed but they actually increase the depression and often cause convulsions and even sudden cessation of respiration and death Coramine® aggravates rather than diminishes respiratory and circulatory depressions of individuals anesthetized with a barbituric acid derivative (85) Drinker (129) states At the present time (1945) there is no substance which can be given by injection which benefits the breathing significantly

At the moment there is no substance which increases the sensitivity of the respiratory center to its normal stimulus—carbon dioxide If such a drug could be discovered then we might have something of real worth Further if it can ever be shown that any such drugs have a specific detoxifying effect on depressant agents their use will be well indicated The role of analeptics in the treatment of respiratory depression is at this time relatively unimportant When used at all *they should be employed with extreme caution* and then only in conjunction with other much more satisfactory means of maintaining the respiratory exchange The prime effort as always should be to better oxygenate the depressed patient and to remove from him accumulated carbon dioxide

C STAGES OF RESPIRATORY DEPRESSION

Flagg (159) divides acute deprivation of oxygen into stages (1) depression (2) spasticity and (3) flaccidity Coryllos (104) lists four phases as (1) period of primary apnea (2) period of dyspnea (3) the period of terminal apnea and (4) the period of failure of the heart

It is impossible however to define arbitrarily phases of acute oxygen deprivation to cover all circumstances for much depends upon the means by which interference with oxygen uptake was first produced The duration of the response is dependent upon the mode of occurrence and the intensity of the deprivation The patient s physical state will also alter the duration and character of the manifestations of such deprivation

1 *Atmospheric Hypoxia*

If the oxygen deprivation is acute, there is a period of dyspnea followed by convulsions and terminal apnea

2 *Tidal Hypoxia*

a *Central—Disease*

If due to cerebral lesions convulsions may be an important manifestation A period of spasticity may be apparent in meningitis With medullary paralysis, there is apt to be early depression

b *Central—Drug*

In acute deprivation of oxygen due to narcotics and anesthetics depression is followed by terminal apnea without an intervening period of spasticity

c *Obstruction*

In patients with respiratory obstruction the response is dependent upon the degree of obstruction If the obstruction is not complete there will be a period of dyspnea followed by spasticity and then terminal apnea It is important to note that during the period of dyspnea the untrained observer may conclude that the patient is in effect making effective respiratory efforts for with each inspiratory effort the abdomen rises This movement however is accompanied by a sinking in of the thorax and is the result of efforts to overcome the obstruction To the trained observer this means rather complete respiratory obstruction

d *Altered Mechanisms*

Convulsions are followed by a period of flaccidity and terminal apnea If the depression is due to intercostal paralysis whether from anterior poliomyelitis or spinal anesthesia there may be no period of increased muscle tone There is an increased activity of the diaphragm with the development of paradoxical respiration The thoracic cage sinks during inspiration Spasticity is not a common characteristic under these circumstances

3 *Alveolar Hypoxia*

a Consolidation

b Atelectasis

c Pleural effusions

These states are characterized by tachypnea followed by dyspnea Here too a period of spasticity is often lacking Dyspnea may be followed by terminal apnea

d Pulmonary edema

Tachypnea and dyspnea are common characteristics A period of spasticity is not usual

4 *Hemoglobic Hypoxia*

a Hemorrhage

Tachypnea may not always appear Dyspnea is usually absent Spasticity is rare

b Carbon monoxide poisoning

There may be a period of respiratory depression, followed by a period of seemingly normal respiration followed by terminal apnea

5 *Stagnant Hypoxia*

a Cardiac failure

b Peripheral vascular failure

Tachypnea and some degree of dyspnea may be apparent Periods of spasticity are unusual

From the above it is apparent that no definite stages can be defined The attendant must keep in mind the etiological circumstances of the oxygen deprivation

D METHODS OF ARTIFICIAL RESPIRATION

The ancients recognized that there is an interval between complete cessation of respiration and eventual demise Mouth to mouth breathing was known in Biblical times (II Kings 4 33–34) Biggs (66) states When Elisha a prophet of Ancient Israel restored the life of a Shunamite woman s boy by blowing his breath into the mouth of the child he forced oxygen and carbon dioxide into the lungs under pressure In the Babylonian Talmud it is stated that a newborn infant who failed to breathe was to be gently swung in a hammock in an effort to restore respiration The modern counterpart of this form of artificial respiration is the method of Eve

Artificial respiration by means of a mechanical device has been used since 1788 when John Hunter experimented with a bellows for this purpose (319) This is probably the first of the mechanical methods for the production of pressure breathing The first of the manual methods of artificial respiration the Silvester was introduced in 1858 It wasn t until 1903 that Schaefer introduced the method known by his name Meltzer and Auer recommended constant endotracheal insufflation as a means of artificial respiration in 1911 Two years later Meltzer recommended intermittent

insufflation for this same purpose (272) Eve proposed the rocking method in 1932 The Neilsen method was proposed in the same year and the Thompson Girdlestone hip raising method was advocated in 1935 (371) The hip rolling method of Emerson was proposed in 1948

The early methods were not satisfactory and the need for better methods had long been appreciated Portable automatic devices for intermittent oxygen delivery have been developed to be carried by rescue squads or be distributed in areas such as delivery rooms, or rescue stations on beaches, where they may be immediately available The need for prolonged artificial ventilation was recognized by Drinker and Shaw (131), who modified the barospirator of Thunberg This apparatus is large, and not readily transportable The need for smaller automatic cycling devices which would produce intermittent positive pressure breathing (IPPB) was apparent The necessity to oxygenate aviators at high altitudes was an important stimulus for the development of such equipment

Ideally one would wish to have at hand all the necessary equipment when performing ventilatory resuscitation More often than not however the need to revivify an individual occurs when proper equipment is not available One should not wait to obtain such equipment for the need to artificially establish ventilation is immediate Nicholson (285) states The one fact regarding resuscitation which must be emphasized above all others is the importance of speed The fact that five minutes after breathing has stopped the chances of revival have become almost negligible means that in the great majority of cases artificial respiration must be initiated by the man on the spot with equipment immediately available viz his two hands For this reason it is necessary to describe in some detail methods which although not fully satisfactory may be the only ones that can be employed under the circumstances

1 MOUTH TO MOUTH BREATHING

Air can be blown into the lungs of a non breathing individual by mouth to mouth respiration This method is always available and may serve until aid or additional equipment is forthcoming The operator stands or kneels to the left of the patient s head By

means of the fingers of his right hand he compresses the nostrils of the apneic individual With the fourth and fifth fingers of his left hand he supports the patient s jaw The thumb and other two fingers of his left hand cups the patient s mouth Direct contact

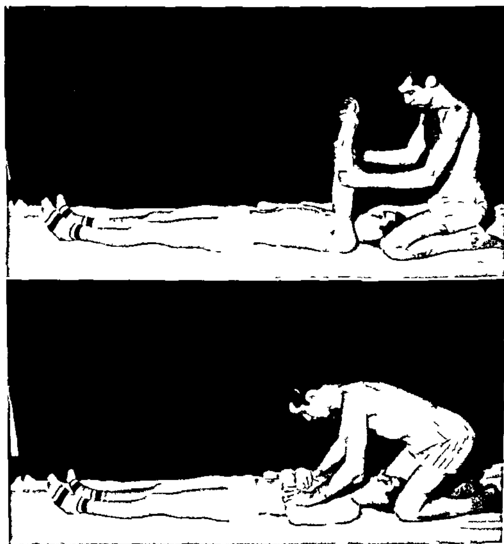


Figure 78 Silvester method of artificial respiration

with some degree of pressure is required between the operator s and the patient s lips The operator blows into the patient s mouth at the rate of about 15 times per minute The patient s tongue may often serve to obstruct the inflow of air and if possible an oral airway should be introduced

2 MANUAL METHODS

a Silvester

The patient lies supine (Figure 78), with head and neck extended The operator places himself at the head of the patient and grasps his arms at the elbows pressing firmly and steadily against the sides of the chest to produce expiration The arms still grasped by the elbows are raised in the long axis of the patient s body to effect an enlargement of the thoracic cage This produces inspiration After a wait of a couple of seconds the arms are then returned alongside the patient s chest and compression is again exerted This cycle of events should be repeated approximately 15 times per minute This method has the advantage that it can be started immediately and requires but one operator It is of disadvantage however, that the patient lies supine and can obstruct his airway the procedure is exhausting to the operator and fractured ribs have been reported

Beecher (59) suggests a modification of the Silvester method which is not as tiring to the operator With the patient supine the operator kneels with one knee in the patient s crotch and the other knee outside the patient s thigh He grasps the patient at the elbows and pushes them above the patient s head The patient s arms are then returned to his sides and the operator exerts pressure on the lower chest and upper abdomen to help expel the air from the lungs

b Schaefer

The patient lies prone (Figure 79) with one arm extended directly overhead The other arm is bent at the elbow and with the face turned outward the head rests on the hand and forearm so that the nose and mouth are free The operator straddles the patient s thighs and places the palms of his hands on the small of the back with fingers resting on the ribs the fifth finger just touching the lowest rib With arms straight the operator swings his body forward so that his weight is gradually transferred to his arms and thus upon the patient causing expiration The operator then relieves his pressure quickly and swings backward to the original position After a few seconds the procedure is repeated

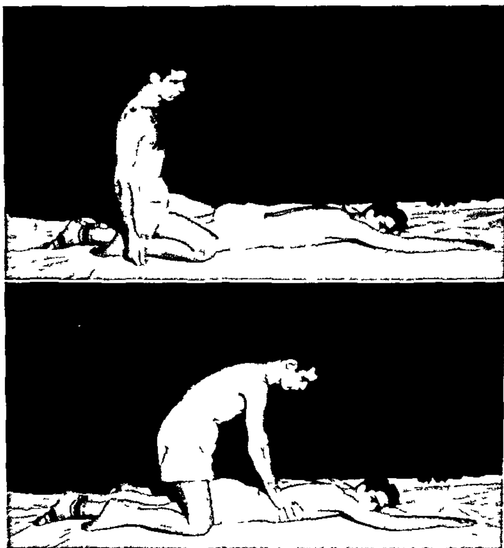


Figure 79 Schaefer method of artificial respiration

Here too the cycle should be repeated about 15 times per minute The method can be applied immediately and it requires but one operator It has the disadvantage that the tidal volume created is small since there is active expiration with only passive inspiration and here also fractured ribs have been reported

c. Nielsen

The patient lies prone with hands placed under his forehead (Figure 80) (181) The operator grasps the elbows and raises them to create an active inspiration The arms are released and pressure is applied over both scapulae to produce expiration

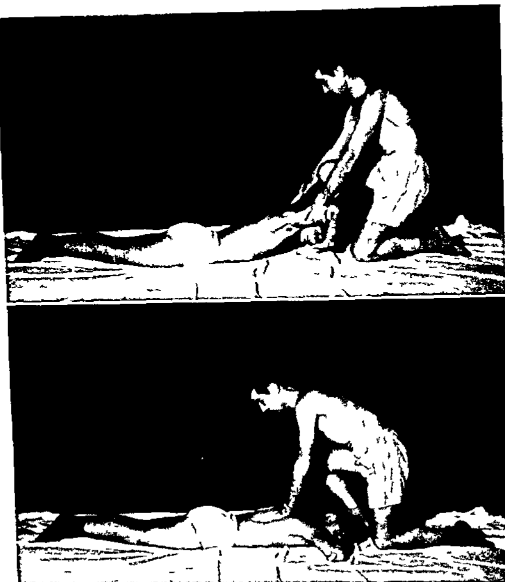


Figure 80 Nielsen method of artificial respiration

Advantages of this method are that it can be immediately instituted with one operator and a good tidal exchange is created The procedure is fatiguing to the operator and injuries have resulted to the patient

d Schaefer Nielsen Drinker

With the patient in the above position (Figure 81) one operator applies the prone pressure method of Schaefer Another operator alternately raises the patient s elbows This procedure can be performed immediately and good tidal exchange is produced A dis

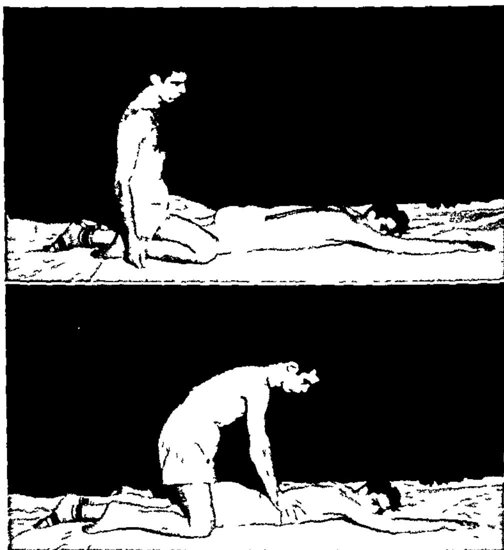


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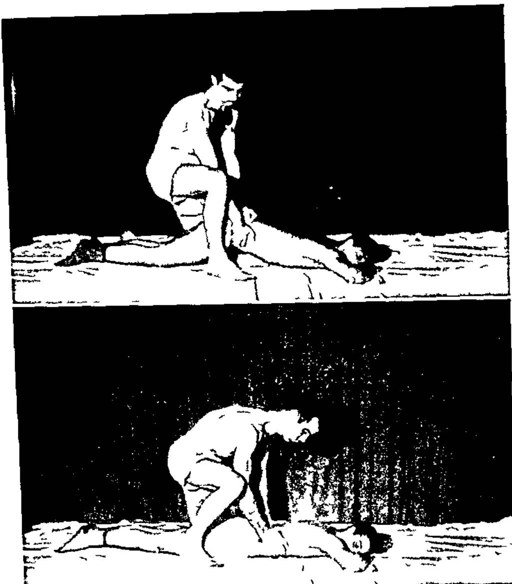


Figure 80 Shaefer Emerson Ivy method of artificial respiration

stone * method to be later described is alternated with pressure exerted on the lower part of the thorax as in the Schaefer method This combination of methods is an improvement over the Schaefer method alone in that pulmonary ventilation is improved and but a single operator is required The effort in elevating the hips for a long period of time however is fatiguing

It should be noted that in normal respiration inspiration is active and expiration is produced by the elastic recoil of the pa

* Though Girdlestone and then Thompson described the hip raising method it was later modified by Emerson

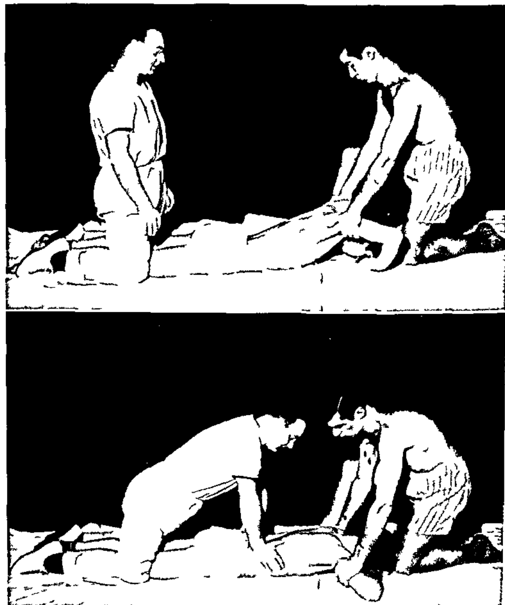


Figure 81 Schaefer Nielsen Drinker method of artificial respiration

advantage is that the procedure requires two operators The method is moderately fatiguing and patients have been injured

e Schaefer Emerson Ivy *

In this method with the patient prone (Figure 82) the lifting and lowering of the hips as in the Thompson Girdle

* The combination of methods was so termed by Gordon *et al* (Gordon A S Fainer D C and Ivy A C Artificial Respiration *J A M A* *144* 17 1455–1464 December 23 *1950*)

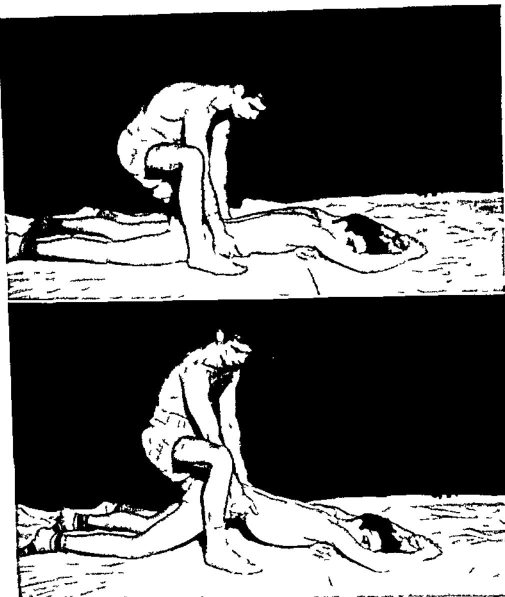


Figure 83 Thompson Girdlestone method of artificial respiration

of the chest The operator places his hands under the iliac spines and raises the patient s hips about 15 times a minute The pelvis should be sufficiently elevated off the ground so that the patient s back arches and the abdomen sags downward (Figure 83) In lifting the hips the spinal column and abdomen act as a bel lows Further the diaphragm is drawn down by sagging of the abdomen The combination of these two effects results in ventila tion

In 1948 John Haven Emerson (143) modified the hip lifting

tient's lungs and thoracic cage. In the manual methods of resuscitation, however, expiration is accomplished by compression of the thoracic cage, and inspiration is dependent upon elastic recoil. One of the great disadvantages to manual methods, therefore, is that elastic recoil of the thoracic cage is dependent almost entirely upon muscle tone, and in cases of advanced hypoxia muscle tone may be entirely lacking.

f. Eve

Eve (118), concerned with the inadequacy of the Silvester and Schaefer methods for the resuscitation of the drowned, evolved the method of resuscitation known by his name. Two pieces of equipment are necessary, a stretcher and some form of trestle. The patient is laid prone on the stretcher with arms extended overhead. The wrists and ankles are lashed to the stretcher with the patient's head turned to one side. The mid point of the stretcher is placed on a trestle and the stretcher then rocked 30 degrees in each direction about 10 times a minute. By this means a tidal exchange can be created because the weight of the abdominal contents pushes and pulls the diaphragm up and down like a piston.

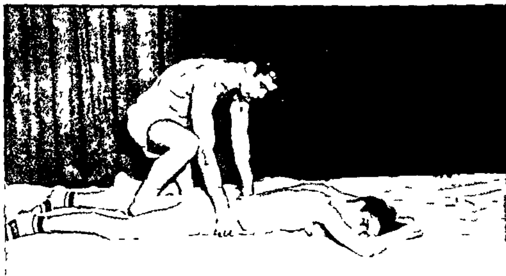
Eve states that this method is an aid to the circulation. He contends that during the head down tilt the blood will course upward in the arteries, closing shut the aortic valve, and that some will go into the coronary circulation and some of the blood will also be diverted to the brain. Alteration of position gives an intermittent flow to these parts. He quotes experiments of Sir Leonard Hill who showed that blood flow to the brain can be maintained by this maneuver.

Of definite disadvantage is the time required to gather the equipment. Once instituted the method needs but one operator, but it requires several to get the procedure started. The tidal volume obtained is not as large as with other methods and a great disadvantage is the fact that stomach contents may be regurgitated into the pharynx and thus aspirated.

g. Thompson Girdlestone

In the Thompson Girdlestone method (374), suggested in 1935, the operator stands astride the prone patient, who has had a folded coat or small pillow placed beneath the clavicles and upper part

Figure 85 Hip raising method of artificial respiration—Emerson



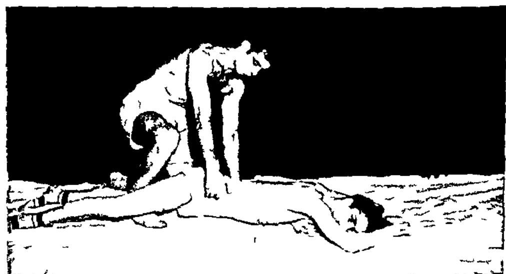


Figure 84 Hip rolling method of artificial respiration—Emerson

method of artificial respiration The operator stands to one side of the prone patient facing his head Reaching across the patient and placing his fingers under the iliac crest the operator rolls the patient toward him at about ten to twelve times per minute (Figure 84) This rolling produces a respiratory exchange If the victim is heavy or if resuscitation is required for a long interval of time a towel or belt is passed under the patient s hips One operator on each side grasps one end of the towel or belt and the patient is raised and lowered at about the same rate as above (Figure 85) If but one operator is available one end of the support can be

Figure 85 Hip raising method of artificial respiration—Emerson

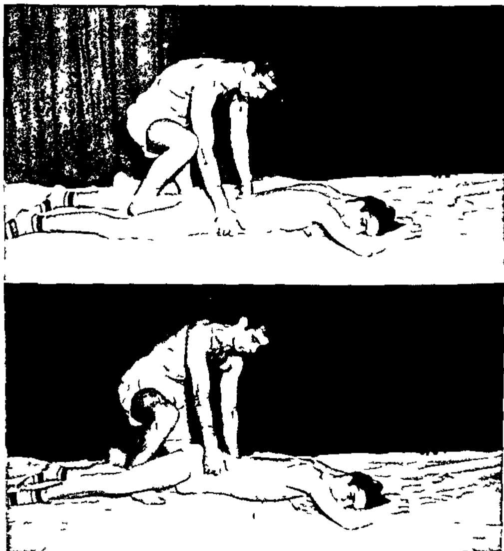
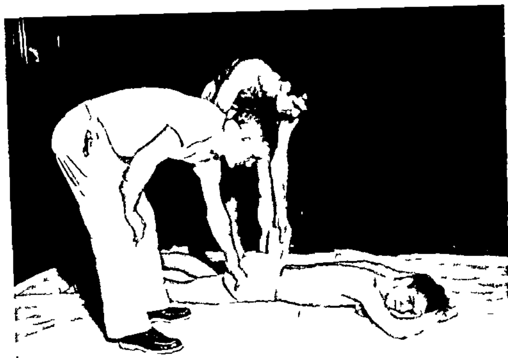


Figure 84 Hip rolling method of artificial respiration—Emerson

method of artificial respiration The operator stands to one side of the prone patient facing his head Reaching across the patient and placing his fingers under the iliac crest the operator rolls the patient toward him at about ten to twelve times per minute (Figure 84) This rolling produces a respiratory exchange If the victim is heavy or if resuscitation is required for a long interval of time a towel or belt is passed under the patient s hips One operator on each side grasps one end of the towel or belt and the patient is raised and lowered at about the same rate as above (Figure 85) If but one operator is available one end of the support can be



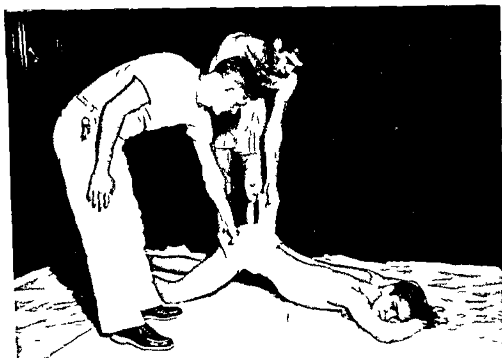


Figure 85 Hip raising method of artificial respiration—Emerson

looped about a doorknob or the arm of a chair Hip-lifting or rolling methods are more physiologic than the prone pressure methods since the former expand rather than compress the relaxed thoracic cage

Gordon *et al* (181 182) compared the different methods on warm corpses within one hour after cessation of the heart beat The manual methods which were designed to produce both inspiration and expiration produced almost twice as much ventilation as those that did not

These workers have shown that not only is it important to compress the chest actively to cause expiration but it is further necessary to expand the chest actively to create a satisfactory inspiration They found the Nielsen method was more effective than the Schaefer as were the hip lifting maneuvers of Thompson Girdlestone and Emerson When the hip lifting maneuver is added to the chest pressure maneuver a very satisfactory tidal exchange can be produced

Gordon *et al* (182) found that the various methods of resuscitation resulted in the following tidal exchanges

Silvester	520 cc
Schaefer	185 cc
Eve	225 cc
Nielsen	580 cc
Schaefer Neilsen Drinker	575 cc
Emerson	270 cc
Schaefer Emerson Ivy	530 cc

Motley Cournand *et al* (279) found the Schaefer method was grossly inadequate On three individuals they obtained, by this method tidal exchanges of 78 cc 50 cc and on the last 140 cc By the Eve method they obtained a tidal volume of but 50 to 60 cc

Eve (148) reports that the Royal Navy found the Schaefer method to be rarely successful although it had been practiced by trained individuals In tests on the warm cadaver Schaefer s method yielded only 30 cc and Silvester s method 200 cc On two anesthetized individuals the Schaefer method yielded 660 cc and the Silvester 930 cc He found the Silvester method is the better of the two and should be the one to be employed in emergencies

or until other equipment can be made available Employing his own method he obtained 600 cc per tilt In an instance where an anesthetized individual was exposed to the various forms of artificial respiration the yields were Schaefer 310 cc Silvester 100 cc and Eve 580 cc

Comroe and Dripps (98) compared the Schaefer prone pressure method and the Eve tilting method on two apneic individuals They found that tidal air produced by the Schaefer method varied from 71 5 to 117 cc and by the Eve method from 286 to 500 cc It was apparent to them that the Schaefer method failed almost completely to ventilate these two unconscious apneic individuals

Kreiselman (238) correctly points out that prone positioning of patients for resuscitation is of disadvantage for in this position the thorax is splinted by the weight of the patient This may overbalance the reported advantages of better maintenance of airway and more ready drainage of secretion from the lung obtained by prone posture It is certainly true that under ideal conditions as prevail in the operating room artificial respiration is best performed with the patient supine

The Meltzer Auer tracheal insufflation method has been critically studied (98) In this method high volumes of oxygen are delivered by means of an endotracheal catheter to the bifurcation of the trachea In two experiments employing a flow of oxygen of 6 to 11 liters per minute the arterial oxygen saturation was 95 8 and 90 per cent This was as good as could be expected There was however a marked accumulation of carbon dioxide with consequent acidosis The carbon dioxide tensions in the arterial blood rose to 314 and 152 millimeters of mercury and the arterial pH fell to 6 67 and 6 86 The point is made again that artificial respiration therefore should not only serve to oxygenate the blood but should enable the individual to get rid of accumulated carbon dioxide

3 INTERMITTENT POSITIVE PRESSURE BREATHING (IPPB)

Artificial respiration is most commonly administered by intermittent insufflation of oxygen The pressure exerted to inflate the lungs intermittently may be the result of manual compression of

looped about a doorknob or the arm of a chair Hip lifting or rolling methods are more physiologic than the prone pressure methods since the former expand rather than compress the relaxed thoracic cage

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index and middle fingers cause downward pressure on the face mask (Figure 86) The operator s right hand compresses the rubber bag rhythmically at about 12 to 15 times per minute To prevent overdistention of the bag by the inflowing gases the mask is occasionally raised slightly off the patient s face to allow for leakage The excess flow is necessary to prevent carbon dioxide accumulation The amount of pressure exerted should be just enough to force oxygen into the patient s lungs and to produce what to the

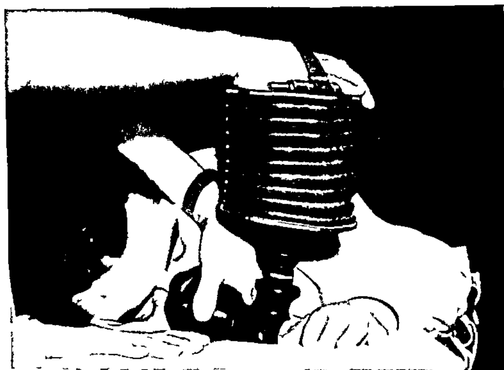


Figure 87 Kreiselman hand bellows respirator

patient would be a normal tidal exchange One should be careful not to exert too much pressure or to deliver too large quantities of oxygen into the lungs of a child or an infant

(2) Bellows The respirator proposed by Kreiselman (239) (Figure 87) consists of an expansible bellows type bag of about 1500 cc capacity and a mask Placed between the two is a one way valve With the bag in resting position the patient can breathe the air freely out of and into the room The bag is elevated by means of a hand strap and as it is elevated room air is sucked into a valve at the top of the bag When the bag is compressed the air therein is

a bag or from compressed gases Some of the apparatus which *employ compressed gases are automatic in cycling performance* Most of them produce intermittent positive pressure alone whereas some also have a negative pressure phase in the cycling performance It has been reasonably well established (63) that a pressure of 15 millimeters of mercury applied in alternate five second cycles can be well tolerated for periods of six hours and that pressures of 25 millimeters of mercury during similar periods

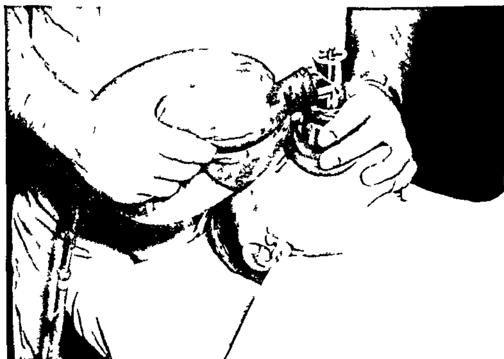


Figure 86 Bag and mask method of artificial respiration

produce a sensation of substernal distress in relaxed conscious adults The pressure required to overdistend the lungs of healthy adults and thus rupture capillaries with subsequent production of gas emboli appears to be in excess of 30 millimeters of mercury

a Pressure by Manual Means

(1) **Bag and Mask** Oxygen flowing at a rate of 4 to 8 liters per minute is led by means of a rubber tube to a collecting bag which is attached to a tightly fitting mask The last two fingers of the left hand of the operator support the patient's jaw The thumb

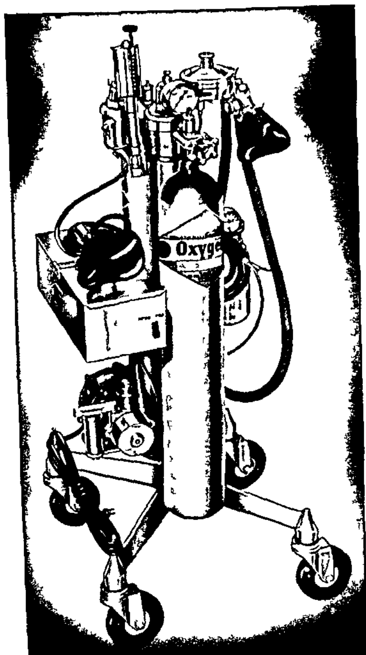


Figure 88 Kreiselman adult respirator

mittent insufflation be produced by depressing the valve but a continuous flow of oxygen can be delivered should the patient begin to breathe on his own

(*b*) *Kreiselman Infant Resuscitator* This apparatus (Figure 89) is admirably suited for infant resuscitation The bassinette is

delivered to the patient s lungs A safety valve limits to no more than 20 millimeters of mercury the pressure that can be built up

When the pressure of the hand against the bag is released at the termination of inflation the valve leading to the bag is immediately closed and the patient exhales about the valve There is no chance for rebreathing and there is thus no hazard from accumulated carbon dioxide except as the result of dead space in the mask itself

Oxygen is desirable and if available it can be admitted through a nipple at the top of the bag A flow of 1 to 8 liters per minute is adequate The bellows is compressed at about 15 times per minute

The apparatus is supplied with an elbow so that it can be used with the patient lying on his side or even prone for purposes of drainage The entire equipment weighs only about two pounds Since it is readily portable it has proven itself an extremely valuable aid to resuscitation It is relatively inexpensive and could replace with benefit many of the complicated and more costly forms of apparatus Its wide distribution in hazardous areas is strongly indicated

The sliding valve as originally designed had been considered unsatisfactory because the inexperienced operator may block proper functioning of the valve by getting his hand in the way of the sliding part This feature has now been corrected by a flange arrangement The pressure curve produced by this apparatus is shown in Figure 93 TYPE VI

b Pressure by Compressed Gases

The inflation instead of being the result of manual compression of the bag or bellows can be produced by the pressure from a cylinder of oxygen The delivered pressure in some of the apparatus can be employed to cause intermittent insufflation by manipulation of some mechanism In others the insufflation is automatically cycled

(1) Non cycling (*a*) *Kreiselman Adult Respirator* (Figure 88) This apparatus (240) is capable of delivering oxygen up to a pressure of 25 millimeters of mercury and has two cylinders of oxygen a reducing valve system a flowmeter and an electric suction An important advantage to this apparatus is that not only may inter

may, on occasion be necessary to initiate respiration, but such a pressure should be dropped when the apparatus is employed for continued use The rhythm and rate of operation are controlled by the operator Should the newborn begin breathing a continuous flow of oxygen is substituted for the intermittent insufflation

(c) *Miller Infant Resuscitator* This is a very simple and inexpensive means for the intermittent insufflation of the newborn



Figure 90 Use of Miller respirator

(Figure 90) Pressure control depends upon the weight of a metal ball fitting into its seat built into the flow line The ball limits the amount of pressure which can be delivered Oxygen at a flow of 4 to 5 liters per minute passes by the valve arrangement to a face piece (Figure 91) By application of the mask pressure is built up within the system to a point where the ball is raised from its seat Raising of the mask results in exhalation This procedure is carried out rhythmically Of disadvantage is the fact that a continuous flow of oxygen cannot be administered without raising the mask The apparatus is well advised and properly employed

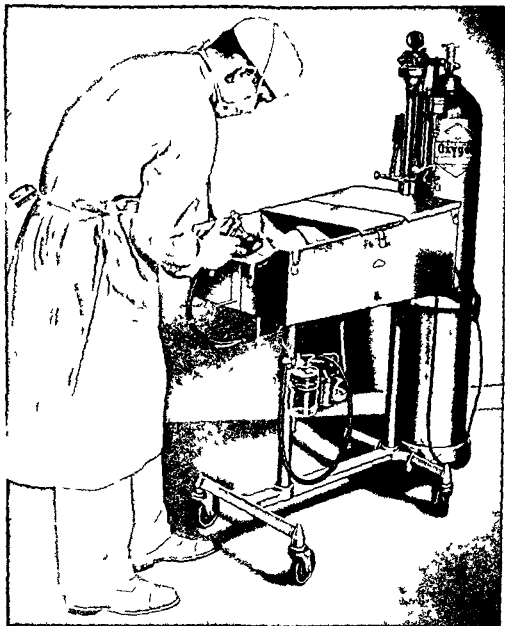


Figure 89 Kreiselman infant respirator

electrically heated There is a tilting platform to encourage drain age and here too an electrically driven aspirator is incorporated in the equipment By applying the face piece oxygen can be de livered intermittently under carefully controlled pressures The pressure recorded on a water manometer may be regulated up to 16 millimeters of mercury A pressure of 15 millimeters of mercury

the various phases of respiration are less deleterious than others and a proper pressure curve has been determined The negative phase of certain of these respirators has effects which are both advantageous and disadvantageous to circulation

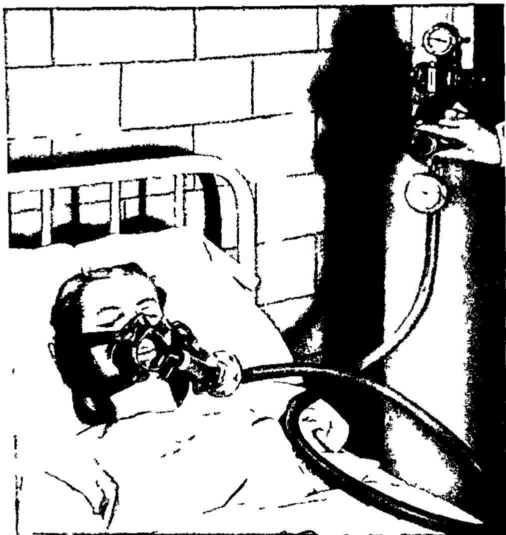


Figure 92 Pneumatic Balance Respirator

Both the automatic devices and the hand operated bellows (Kreiselman) type have been studied by Motley *et al* (279) In this magnificent study these authors determined the pressure curves produced by the various forms of apparatus and their influence upon ventilation and circulation These authors considered the following seven different forms of apparatus

will produce better results than many other more costly pieces of equipment

(2) Cycling Apparatus has been designed to produce intermittent positive pressure breathing automatically The cycling mechanism is controlled by the tank pressure Most such equipment will deliver positive pressure only Some have a positive and a negative phase Although the respiratory exchange developed by all such

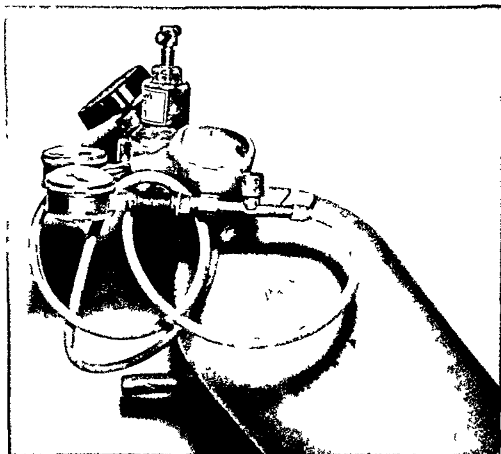


Figure 91 Miller respirator showing spill valve tubing and face piece

apparatus is in general satisfactory it must be noted that several undesirable side effects may appear

The apparatus deliver 100 per cent oxygen The continued use of such high concentrations of oxygen has been considered in the section on Oxygen Poisoning A respiratory exchange greater than normal may be produced with consequent too great reduction in carbon dioxide Certain pressure relationships or duration of

nism converts continuous positive pressure from the cylinder into intermittent positive pressure to the patient The pressure pattern developed is shown in Figure 93

TYPE II *Pressure sensitive spring loaded valve* This is an experimental mechanism similar to that of TYPE V, without a Venturi valve It is similar to TYPE I in the breathing pattern produced as well as in its influence on respiration and circulation The pressure curve determined is shown in Figure 93

TYPE III *Flow sensitive Aviation Model* In this the intermittency is the result of the flow sensitive valve It was developed by the Army Air Corps In Figure 93 is a tracing of the pressure curve produced

TYPE IV *Flow sensitive research model* This is similar to TYPE III but it has many valuable features which render adjustment of many variables possible This is essentially a research tool for the following variables can be controlled (1) Line pressure (2) Inspiratory cycling rate (3) Expiratory cycling rate (4) Inspiratory flow rate (5) Expiratory flow rate and (6) Expiratory pressure Because of this large control mechanism various pressure curves can be developed as in Figure 93 4A 4B 4C

TYPE V *Suck and blow* This mechanism is controlled by a spring loaded pressure sensitive valve for the development of positive pressure and a Venturi valve for producing the negative phase Commercial examples of this form of apparatus are the Emerson E & J and Stephenson This apparatus produces a negative pressure at the beginning of inspiration which becomes positive up to a certain peak pressure at which point reversal takes place During expiration the pressure decreases gradually back to the starting point as shown in Figure 93 These apparatus are usually pre fixed so that there can be no control in varying the degree of positive or negative pressure The suck and blow apparatus studied by these authors had a fixed positive pressure at 13 5 millimeters of mercury and a negative pressure at −11 1 millimeters of mercury An apparatus of this general type which needs further evaluation is that manufactured by Emerson (Figure 94) which develops a mask pressure of +13 to only −2 millimeters of mercury This apparatus is readily portable inexpensive and would seem to have a place

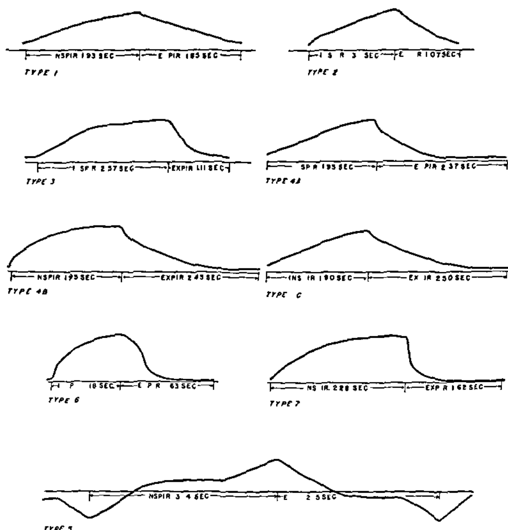


Figure 93 Mask pressure curves (After Motley H L Cournand A Werko L Dresdale D T Himmelstein A and Richards D W Jr Intermittent Positive Pressure Breathing A Means of Administering Artificial Respiration in Man *J A M A*, *137* 370–382 May 22 1948)

TYPE I Pressure sensitive air balanced valve
TYPE II Pressure sensitive spring loaded valve
TYPE III Flow sensitive Aviation Model
TYPE IV *Flow sensitive research model*
TYPE V Suck and blow apparatus
TYPE VI Hand operated slow apparatus
TYPE VII Hand operated fast apparatus

TYPE I *Pressure sensitive air balanced valve* This is an automatic device and administers intermittent positive pressure It is controlled by a pressure sensitive air balanced valve It is known as the Pneumatic Balance Resuscitator (Figure 92) This mecha

cardiac catheter and cardiac output was calculated by applying the Fick formula The subjects were normal trained volunteers unanesthetized conscious subjects patients in deep coma and patients in complete apnea

Influence of Various Respirators on Ventilation and Gas Exchange

On conscious subjects there was an increase in pulmonary ventilation from 23 3 per cent with Type I to 105 per cent with Type IV The increased ventilation was due to an increase in tidal volume When employed on patients in deep coma the automatic respirators produced adequate ventilation It was noted that patients with a gasping type of respiration required a very high flow rate of short duration about 0 4 to 0 6 seconds with a maximum peak flow during this interval of up to 80 to 120 liters per minute Type IV the flow sensitive research model was the only respirator with sufficient instantaneous flow capacity to eliminate the negative phase at the beginning of inspiration due to additional inspiratory effort

They found that the Pneumatic Balance Resuscitator was the only automatic respirator considered safe enough to be left for extended periods of time with a minimum of ward supervision on patients in coma In one instance this apparatus was used for 79 hours continuously with no demonstrable ill effects in the treatment of a patient with barbiturate poisoning

Twenty one completely apneic subjects were studied 18 after death and three still living In all but one instance adequate ventilation was sustained Failure in the one instance was due to a foreign body in the upper trachea

Some of the apparatus studied performed better in overcoming breathing resistance in the upper part of the pharynx than others Types III and IV have this characteristic Types I and II tolerated airway obstruction slightly better than Type V Type V has a tripping mechanism which makes audible noises when there is an obstruction This latter feature may be considered desirable if one needs audible signals to inform one whether or not respiration is being artificially performed but too often the tripping mechanism starts in the presence of a degree of obstruction readily overcome by the other apparatus

TYPE VI *Hand operated, slow* This is the Kreiselman apparatus previously described (Figure 87) As tested by these authors the valve opened when positive pressure reached 17 5 millimeters of mercury When the valve opens, expiration takes place rapidly and the mask pressure drops to that of the atmosphere (Figure 93)

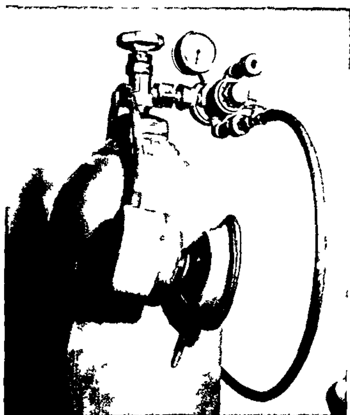


Figure 94 Suck and blow Emerson apparatus

TYPE VII *Hand operated, fast* This is similar to the Kreiselman apparatus In this model the expiratory pressure drops more rapidly because of a change in the valve (Figure 93)

The above seven types of equipment with the exception of the modification of the Emerson spoken of above were studied by Motley *et al* (279) Respiratory gas exchange was studied blood samples were analyzed for oxygen content oxygen capacity and carbon dioxide the pH the oxygen saturation and pCO_2 Blood samples were obtained from the right ventricle by means of a

During artificial respiration by intermittent positive pressure breathing there is an increase in the intrathoracic pressure during inspiration The intrapulmonary pressure decreases during expiration During the inspiratory phase where there is an increase in intrapulmonary pressure there is a decreased output from the right side of the heart which is made up during the expiratory phase On the left side of the heart the reverse occurs The authors state quite emphatically that during intermittent pressure breathing the pressure should not only be low during expiration but that this phase of low pressure in the thorax should be of sufficient length and that the total expiratory interval should allow a sufficiently large number of heart beats to compensate for the reduction in output which occurs during the inspiratory period of rising pressure In the TYPE I symmetric curve (Figure 93) with inspiratory and expiratory time almost equal the cardiac output is affected throughout the entire cycle Since there is an intrapulmonary positive pressure throughout the respiratory cycle there is a constant diminution in the venous return of the blood to the right heart The greater the increase in the intrapulmonary pressure the greater will be the reduction in cardiac output with this form of respirator The TYPE III curve has a quick pressure drop in expiration which permits the right heart early in expiration to compensate for part of the loss incurred during inspiration but this compensation is not complete since the pressure does not return to that of the atmosphere and the expiratory time is too short The TYPE IV curve also has a quick drop on the expiratory phase and compensation is thus encouraged TYPES VI and VII have rapid drops to atmospheric pressure and are satisfactory If during the expiratory phase the pressure is allowed to drop to that of the atmosphere and if the expiratory time is long enough complete compensation occurs

These same authors list the characteristics of ideal respirator equipment

1 They should be simple and sturdy in construction

2 The mask pressure curve should increase gradually during inspiration up to a peak not greater than 25 centimeters of water Upon reversal the pressure should decrease rapidly to that of the atmosphere

The Influence of the Various Respirators on the Circulation

1 *Heart Rate* It was noted that the heart rate increased more appreciably during the period of increasing pressure than during the period of decreasing pressure During the period of increasing pressure with an average mean mask pressure of 9 3 millimeters of mercury the average increase in heart rate was 10 per cent During the period of decreasing pressure with an average mean mask pressure of 5 1 the average increase in heart rate was approximately 4 per cent With Type IV where the expiratory pressure is dropped rapidly there was no significant rise in the heart rate

2 *Electrocardiogram* There was no significant electrocardiographic change noted

3 *Blood Pressure* The changes in blood pressure during resuscitation with these automatic respirators were not great

4 *Peripheral Vascular Resistance* This was found to be increased with all the apparatus employed

5 *Cardiac Output* Type I produced a decrease in cardiac output of 10 8 per cent The reduction in cardiac output with Type IV was 5 9 per cent With Type III it was 12 9 per cent With Type V there was an insignificant change in cardiac output With especial reference to the negative phase in Type V there was no striking increase in right ventricle net filling pressure There was no evidence obtained that negative pressure during part of the cycle increased cardiac output On two patients in deep coma however it was noted that the suck and blow type of respirator did not produce adverse circulatory effects

The authors summarize the effects of intermittent positive pressure breathing because of changes in intrathoracic pressure as follows

1 During the increasing inspiratory pressure period the venous return to the right heart diminishes

2 During the phase of diminishing expiratory pressure the reverse takes place and

3 The more rapid and complete the pressure drop to zero after a reversal of the peak pressure the greater the filling of the right side of the heart during expiration

During artificial respiration by intermittent positive pressure breathing there is an increase in the intrathoracic pressure during inspiration The intrapulmonary pressure decreases during expiration During the inspiratory phase where there is an increase in intrapulmonary pressure there is a decreased output from the right side of the heart, which is made up during the expiratory phase On the left side of the heart the reverse occurs The authors state quite emphatically that during intermittent pressure breathing the pressure should not only be low during expiration but that this phase of low pressure in the thorax should be of sufficient length and that the total expiratory interval should allow a sufficiently large number of heart beats to compensate for the reduction in output which occurs during the inspiratory period of rising pressure In the TYPE I symmetric curve (Figure 93), with inspiratory and expiratory time almost equal, the cardiac output is affected throughout the entire cycle Since there is an intrapulmonary positive pressure throughout the respiratory cycle there is a constant diminution in the venous return of the blood to the right heart The greater the increase in the intrapulmonary pressure the greater will be the reduction in cardiac output with this form of respirator The TYPE III curve has a quick pressure drop in expiration which permits the right heart early in expiration to compensate for part of the loss incurred during inspiration, but this compensation is not complete since the pressure does not return to that of the atmosphere and the expiratory time is too short The TYPE IV curve also has a quick drop on the expiratory phase and compensation is thus encouraged TYPES VI and VII have rapid drops to atmospheric pressure and are satisfactory If during the expiratory phase the pressure is allowed to drop to that of the atmosphere and if the expiratory time is long enough complete compensation occurs

These same authors list the characteristics of ideal respirator equipment

1 They should be simple and sturdy in construction

2 The mask pressure curve should increase gradually during inspiration up to a peak not greater than 25 centimeters of water Upon reversal the pressure should decrease rapidly to that of the atmosphere

3 The rate of respiration should be between 10 and 20 times per minute

4 The pulmonary ventilation provided should be from 6 to 10 liters per minute

COMMENT

It has been understood for some time that an increase in the intrapulmonary pressure may be harmful to circulation It was shown by Beecher *et al* (60) that increase in intrapulmonary pressure in dogs under anesthesia produces a great rise in venous pressure with a fall in systolic diastolic and mean blood pressure There was also an associated decrease in blood flow through the femoral and carotid arteries Although this situation was well tolerated by animals in good condition the increased pressure was deleterious and even caused death in animals who were in poor condition

Knoefel *et al* (235) demonstrated that an increase in intrapulmonary pressure of 7 millimeters of mercury for three hours leads to a reduction in cardiac output of 41 per cent This is substantiated by the work of Volpitto *et al* (384) who showed that increased intrapulmonic positive pressure greater than 10 to 15 millimeters of mercury if maintained for a prolonged period of time may hinder venous return to the right side of the heart The quoted work of Motley *et al* (279) shows why there is a decrease in cardiac output

Since altered intrapulmonary pressures have such important circulatory effects it is not amiss to review the pressure curves produced by some of the apparatus employed for pressure breathing

The normal intrapulmonary pressure during inspiration is subatmospheric and exhalation is above atmospheric Figure 95 is a simplified representation of normal respiration That phase of respiration in which the pressure is subatmospheric has a two fold function (1) To draw air into the lungs and (2) to draw blood into the thin walled vessels within the chest cage and into the right heart Respiratory curve (Type A) (Figure 96) is produced by an increase of pressure during inspiration alone Unless very carefully controlled such pressure has untoward circulatory effects

for at no time is the intrapulmonary pressure negative Indeed it may never even be as low as atmospheric The pressure may be increased during inspiration by manual compression of the anesthesia bag during inspiration alone or by the use of the Maloney, Crafoord or Mautz apparatus The P B R and the Bennett X 2

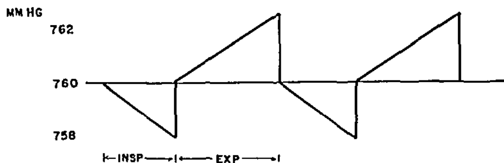
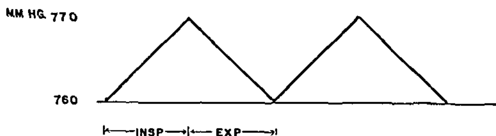


Figure 95 Graphic representation of normal respiration

produce this type of respiration as do the Kreiselman apparatus —the hand bellows the adult respirator and the infant respirator

The development of positive pressure on expiration alone is employed primarily for its effect on circulation Type B (Figure 97) curve is produced by this form of pressure Although the maxi



TYPE A

Figure 96 Graphic representation of inspiratory positive pressure

mum pressure is in the expiratory phase the first portion of inspiration at least is positive pressure breathing Unless carefully developed it may be that no part of the inspiratory phase is negative Apparatus for the development of positive pressure during expiration have been developed by Plesch and by Poulton Barach developed the choked disc to serve as an obstruction to expiration and another apparatus by which the patient exhales under a col

3 The rate of respiration should be between 10 and 20 times per minute

4 The pulmonary ventilation provided should be from 6 to 10 liters per minute

COMMENT

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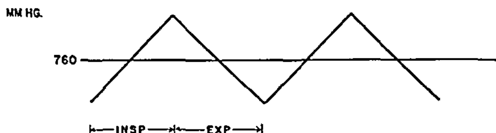
Knoefel *et al* (235) demonstrated that an increase in intrapulmonary pressure of 7 millimeters of mercury for three hours leads to a reduction in cardiac output of 31 per cent This is substantiated by the work of Volpitto *et al* (384) who showed that increased intrapulmonic positive pressure greater than 10 to 12 millimeters of mercury if maintained for a prolonged period of time may hinder venous return to the right side of the heart The quoted work of Motley *et al* (279) shows why there is a decrease in cardiac output

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to breathe with a bag too tight throughout respiration, or if the anesthetist's hand is kept on the bag throughout the phases of respiration The weighted and inverted bag on the Connell apparatus as well as the continuous positive pressure breathing apparatus of Barach accomplish the same purpose

The commonly employed blow and suck apparatuses as the E & J apparatus the Stephenson and the Emerson, produce a curve as in Type D (Figure 99)



TYPE D

Figure 99 Graphic representation of suck and blow respiration

The Drinker Shaw apparatus to be later described though it causes intermittent intrapulmonary negative pressure is said to be a form of intermittent positive pressure breathing The pressure curve developed however is like the normal This latter is also true of the electrophrenic respirator (E P R) to be considered later

Several types of respiratory curves can be developed by the various models of the equalizing pressure chamber of Barach Although the chest remains stationary in this type of apparatus one may however still speak of an inspiratory and an expiratory phase Intermittent negative pressure by the equalizing chamber produces Type E curve (Figure 100) At first glance then the intrapulmonary pressure throughout the respiratory cycle is negative (Type Ea) but if we were to consider the immediate atmosphere in which the patient lives expiration is relatively positive (Type Eb)

Employing the apparatus in the positive and negative phase we obtain Type F curve (Figure 101) in which inspiration is partially positive and negative and expiration is partially negative and positive

umn of water During anesthesia this type of respiration can be developed if the anesthetist causes the patient to exhale against resistance, as by holding the hand on the bag during expiration

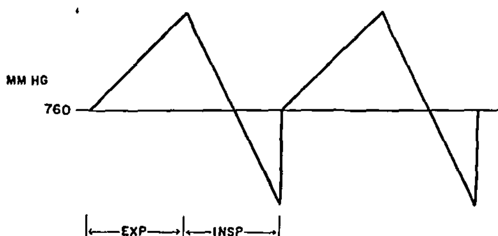


Figure 97 Graphic representation of expiratory positive pressure

or requiring the patient to overcome a weighted or spring valve during expiration

Positive pressure is employed by some throughout the respiratory cycle Type Ca (Figure 98) can be developed wherein the

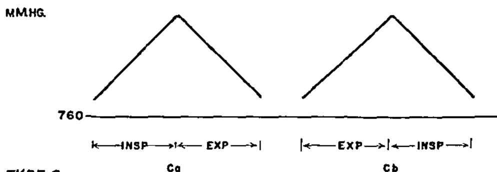


Figure 98 Graphic representation of positive pressure throughout respiratory cycle

pressure increases with inspiration and decreases with expiration or in Type Cb where it increases with expiration and decreases with inspiration Positive pressure throughout the respiratory cycle may be developed during anesthesia if the patient is required

teristics The volume flow should be sufficient to allow for comfortable breathing for the dyspneic patient, since such a subject may require an instantaneous flow rate of up to 100 liters per minute (282) during the early part of inspiration Should the flow rate of the apparatus be inadequate, the patient pulls or leads the apparatus causing a sense of obstruction to breathing Records of patients with Cheyne Stokes respiration show a need of 110 liters per minute Most pressure devices have a flow rate of but 50 liters per minute Should a patient whose needs are greater than this be placed on such apparatus, the inspiratory phase might thus become negative Because of insufficient instantaneous flow characteristics

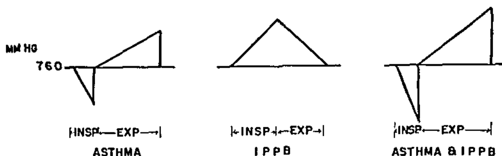


Figure 102 Graphic representation of intrapulmonary pressures of asthmatic patients normal effect of intermittent positive pressure breathing and effect of intermittent positive pressure breathing with insufficient volume flow on intrapulmonary pressure of asthmatic patients

such equipment should not be employed on cardiac patients with dyspnea or on asthmatic patients

Figure 102 shows that the asthmatic patient who is dyspneic develops during inspiration a marked intrapulmonary negative pressure and during expiration a marked increase in expiratory pressure Intermittent positive pressure breathing is ordinarily expected to give a positive pressure on inspiration with the pressure returning to normal on expiration If we subject the markedly dyspneic patient to intermittent positive pressure breathing and if the patient's flow needs during inspiration are not met by the apparatus then the intrapulmonary pressure will not be aided for under this circumstance the intrapulmonary negative pressure during inspiration is made more negative

There would be no objection to the use of such apparatus on individuals who are making respiratory efforts and who do not

We must not lose sight of the fact that abnormal intrapulmonary pressures may sometimes be produced by seemingly simple therapeutic endeavors as for example the B L B apparatus (Figures 50 and 51) wherein by requiring the patient to exhale

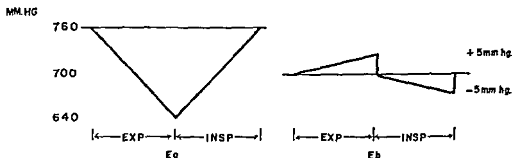


Figure 100 Graphic representation of intermittent negative pressure by equalizing chamber

Ea—pressure within the chamber

Eb—pressure within the lungs

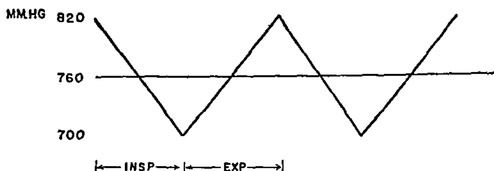


Figure 101 Graphic representation of alternating negative and positive pressure in the equalizing chamber

through a sponge rubber disc the intrapulmonary pressure is increased during expiration If tidal requirements are not met during inspiration some of the tidal air is inhaled through this sponge rubber disc and the intrapulmonary pressure then becomes abnormally negative

An important consideration in addition to the pressure curve produced by the respirators is the magnitude of their flow charac

teristics The volume flow should be sufficient to allow for comfortable breathing for the dyspneic patient, since such a subject may require an instantaneous flow rate of up to 100 liters per minute (282) during the early part of inspiration Should the flow rate of the apparatus be inadequate, the patient pulls or leads the apparatus causing a sense of obstruction to breathing Records of patients with Cheyne Stokes respiration show a need of 110 liters per minute Most pressure devices have a flow rate of but 30 liters per minute Should a patient whose needs are greater than this be placed on such apparatus the inspiratory phase might thus become negative Because of insufficient instantaneous flow characteristics

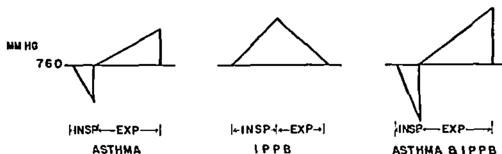


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There would be no objection to the use of such apparatus on individuals who are making respiratory efforts and who do not

require high instantaneous flows The apparatus will cycle with the patient s own respiration because of an incorporated demand mechanism

As pointed out by Motley *et al* (279), the suck and blow apparatus did not show a decrease in cardiac output There was no evidence however, that the negative pressure phase aided the circulation Thompson (372) employing the suck and blow apparatus used radioactive sodium as a tracer substance to see the effect of such respiration on the circulation The animals were anesthetized by intraperitoneal nembutal an endotracheal tube was inserted and the endotracheal tube was then clamped off to insure complete death The animals were then placed on the suck and blow apparatus When radioactive sodium was used it was shown that the suck and blow respirator produced a forward movement of blood which was circulated in the right direction without benefit of cardiac activity Such circulation it is claimed is due to the *filling and emptying of the pulmonary capillaries produced by* artificial respiration It is admitted however that such circulatory movement is in no way comparable in volume or rate with the movement produced by cardiac activity Volpitto *et al* (384) however state There was no evidence to substantiate the theory that resuscitators employing positive negative intrapulmonary pressures could empty or milk enough blood from the capillaries of the lungs to increase the return of blood to the heart effectively They state further Any blood flow which was produced by the resuscitators did not reach the coronary and cerebral arteries Instead blood was pushed toward the extremities and cutaneous areas

The suck and blow apparatus seems to have definite disadvantages Here also as with most intermittent positive pressure devices the flow characteristics of the apparatus is inadequate for patients requiring high flows of oxygen Motley *et al* (282) showed that with such apparatus all of the inspiratory period in dyspneic individuals is apt to be on the negative side showing leading This leading was great and on expiration a degree of positive pressure was produced

Because the suck and blow apparatus does not have sufficient instantaneous flow characteristics and since there is a tendency for

dyspneic individuals to lead the mechanism it is not indicated for such patients Suck and blow respirators are contraindicated on individuals who are still making respiratory efforts since the rhythm may be entirely out of step with the patient s own respiration and thus the respirator may oppose and impede respiration rather than aid it (207) Henderson and Turner (213) note that the negative pressure phase unless kept very low, may induce over ventilation and thus injure the lungs Overventilation also will cause an undue loss of carbon dioxide Negative pressure may lead to congestion and to an increased tendency to edema and hemorrhage into the alveoli (63) Schwerma and Ivy (340), however employed the suck and blow apparatus for one to three hours and found no lung damage from its use Employing a positive pressure of 10 millimeters of mercury and a negative pressure of 9 millimeters of mercury Coryllos (104) concurs with this finding

Thompson (371) believes that the negative pressure exerted by the suck and blow effect is valuable in resuscitation since such suction acts to set up a desirable reflex effect on respiration Drinker (128) in regard to the suck and blow apparatus states In reality the use of lung inflation and deflation to stimulate breathing is a measure requiring medical judgment and experience and cannot be left to an entirely automatic device such as the resuscitator He does believe that since the Hering Breuer reflex is so resistant to oxygen deprivation the best line of attack is through this reflex The intermittent positive pressure breathing initiates it as may also the suck and blow effect but in regard to the latter he states This should not be interpreted as evidence that the appliance is particularly efficient and does no damage to the lungs if continued in use for an hour or more He says that statements which suggest that the circulation is aided by such apparatus are not based upon sound observation

Orth *et al* (293) anesthetized animals with various substances an endotracheal tube was passed and anesthesia deepened sufficiently to produce apnea Eight different methods of artificial respiration were employed He states In all groups regardless of method duration of artificial respiration or anesthetic drug used histologic examination showed areas of atelectasis congestion hemorrhagic infiltration and bronchial spasm Any damage

which did occur in the lungs was reversible and all dogs who were permitted to recover did so without sequelae

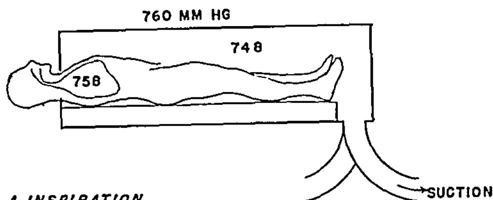
An apparatus not primarily designed for artificial respiration in states of acute oxygen need the Equalizing Pressure Chamber previously described page 206 may here be mentioned as to its possible value in ventilatory resuscitation This chamber was devised primarily to rest the lungs in the treatment of pulmonary tuberculosis Since this apparatus is said to cause an effective oxygen uptake by blood coursing through the lungs it may be of value as a life saving measure No report of its use for this purpose has been made Study in this area is warranted

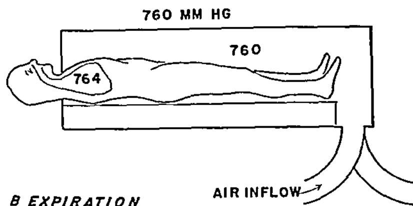
4 INTERMITTENT NEGATIVE PRESSURE BREATHING

a Chamber

In 1929 Drinker and Shaw (131) presented an apparatus in which an individual can be enclosed with the head protruding A rubber diaphragm about the neck separates the head and upper neck from the rest of the body By alternately producing positive and then negative pressure within the chamber artificial pulmonary ventilation can be maintained Later that year (350) a similar apparatus especially designed for children was presented It was soon realized that all that is required in the presence of a free airway is an intermittent negative pressure about the thorax for the elastic recoil of the lungs and chest wall is sufficient to produce a satisfactory respiratory effect The positive phase is not necessary

Figure 103 demonstrates the application of intermittent negative pressure about the body to create artificial ventilation During inspiration (A) by the creation of a partial vacuum within the chamber to about 748 millimeters of mercury the chest wall is raised creating a sub atmospheric pressure within the lung with an associated inrush of air because of the difference of pressure in the room and within the lungs Expiration (B) takes place as soon as the cycling mechanism ceases to function and atmospheric pressure enters the chamber The increase in pressure and the elastic recoil of the chest wall creates a pressure within the lungs greater than atmospheric and air is expelled During the resting phase (C) between the termination of expiration and the beginning of





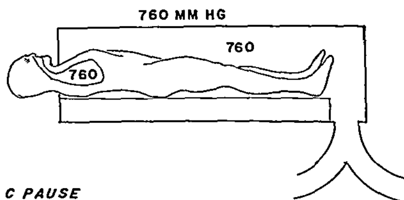


Figure 103 Principle of intermittent negative pressure by Drinker-Shaw chamber

inspiration the pressures within the chamber and the lung are equal

Although respiration is achieved by the creation of intermittent negative pressure about the body, the inspiration thus produced is in effect a form of intermittent positive pressure breathing The creation of a negative pressure of 12 millimeters of mercury within the chamber is equivalent to increasing the atmospheric pressure to the same degree about the head

Regardless of the similarity to intermittent positive pressure breathing the respiration produced by such apparatus is more nearly akin to normal respiration than that attained by intermittent positive pressure breathing

In the Drinker Shaw apparatus inspiration is the result of an increase in the intrapleural negative pressure, whereas in intermittent positive pressure breathing inspiration is associated with a reversal of the normally heightened intrapleural negative pressure to a positive pressure The likelihood is that the effects on circulation may be diametrically opposed under these two circumstances It is probable that intermittent negative pressure on the body has less harmful effects than alternately increased intrapleural pressures

The apparatus has unquestioned advantages because it simulates normal respiration The fact that respiration is created by a heightened intrapleural negative pressure may mean however that in the presence of a partial obstruction to respiration the hazard of pulmonary edema may be increased It has been mentioned (278) that the continued use of the Drinker type apparatus predisposes to the formation of atelectatic areas in the lungs and loss of muscle tone often complicated by the development of bronchopneumonia and pulmonary edema Wilson (396) has described postmortem changes of emphysema and various degrees of congestion and bronchopneumonia in patients treated in the respirator

As with intermittent positive pressure breathing hyperventilation may be produced The alkalosis which may be the result of such hyperventilation because of excess washing out of carbon dioxide must be prevented for such loss may not be offset by the increased oxygen supply to tissue

In the chamber respiration is automatic in cycling performance

There is no incorporated demand mechanism and these patients who are attempting to breathe on their own may have difficulty in fitting their respiratory pattern to that of the machine Some patients because of fright or anxiety cannot relax and continue to fight the respiratory cycle of the machine

The Drinker and similar apparatus such as the Emerson Iron Lung are strongly indicated in the presence of respiratory paralysis where there is no obstruction to respiration A patient who is making respiratory efforts may be placed in the apparatus on a trial basis to see if the machine will take over If the apparatus either does not do so or if the patient will not cooperate then he should be immediately removed and another form of artificial respiration instituted If the patient is apneic and any respiratory obstruction can be prevented by the introduction of an endotracheal tube the apparatus is then indicated

Wilson (397) surveyed between 400 and 500 poliomyelitis patients who were treated in the respirator during the year 1940 One third of this group had simple or intercostal paralysis two thirds bulbar and pharyngeal paralysis Of the former group treated in the respirator less than 20 per cent died Of the two thirds of the patients who had bulbar paralysis and pharyngeal paralysis two thirds died The respirator therefore is clearly indicated only when the difficulty is due to intercostal or diaphragmatic paralysis The patient s own effort to breathe particularly when it is irregular or obstructed as it may be in pharyngeal paralysis may interfere with the respiratory cycle developed by the Drinker type respirator

Of interest here Wilson notes is the fact that the use of this apparatus is too often limited to dire emergencies and as a last dramatic effort to preserve life The apparatus should be used early and before the patient feels desperately in need of help Under these circumstances it is apt at first trial to seem ineffective but in the presence of intercostal or diaphragmatic paralysis one should not readily give up its employment Since it is extremely important that the patient be treated early it is Wilson s feeling that the diagnosis of paralysis be made early Careful watch of the patient will demonstrate early reduction in respiratory capacity by a slight dilation of the nostrils during attempts at inspiration

The patient may avoid speech or talk only by stopping frequently to take a breath Wilson suggests that a therapeutic test is to ask the patient to count and to see how many numbers he can repeat with one breath One should not wait for the appearance of advanced signs of oxygen want, such as dyspnea and cyanosis for these are symptoms of desperate need and indicate the fact that the respirator should have been used long before

Seemingly the problem of artificially ventilating a patient with poliomyelitis in the presence of simple diaphragmatic or intercostal paralysis is solved The problem of maintaining ventilation in other forms of poliomyelitis where there is bulbar or pharyngeal paralysis is by no means near solution



Figure 104 Use of the P B R apparatus to maintain respiration during removal of patients from respirator

Much of the difficulty met in ventilating this latter group of patients is due to the presence of respiratory obstruction The insertion of an endotracheal tube may make it possible for the Drinker Shaw type of apparatus to ventilate such patients adequately An additional disturbing problem and one difficult to handle in this group of individuals is the care of secretions The frequent passage of suction catheters down the endotracheal tube will do much to keep the tracheobronchial tree clear

Many patients will not allow their respiration to synchronize with that of the apparatus They continue to fight the respirator sometimes to exhaustion Although I have not employed curariform agents for such a purpose it might be wise to consider their possible use to paralyze the muscles of respiration so that the respirator may be given a chance to work

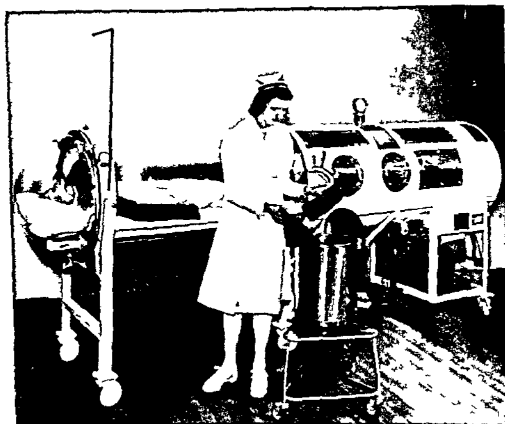


Figure 105 Use of the Emerson Respirator Dome to maintain respiration during removal of the patient from the respirator

Very often in the use of respirators the blood is not sufficiently oxygenated and it is often worthwhile to supplement the respirator with additional oxygen This can be readily brought about if a nasal catheter delivering oxygen is employed in association with this form of respirator

The care of the patient s bodily needs are often a problem with the patient in a respirator Removal of the patient from the respirator for this purpose often leads to distress since during this period the patient may not be breathing To overcome this the

P B R apparatus may be employed as in Figure 104 during the interval of removal from the respirator so that ventilation can be adequately taken care of Emerson has added a Respirator Dome apparatus which can be put into position before opening the chamber to care for the patient s bodily requirements or to employ hot packs (Figure 105) The apparatus then breathes for the patient taking over automatically at the accustomed rate The use of this



Figure 106 Chest model respirator

apparatus as well as the P B R as above stated for this purpose could be also employed during muscle training intravenous therapy and even obstetrics

b Chest Models

By limiting the creation of alternating negative pressure to the area about the thoracic cage as in Figures 106 and 107 one can create a tidal exchange which may be sufficient to carry the patient through a period of emergency Such apparatus is more or less readily portable and would seem to have a possible place in the institution of life saving measures under emergency conditions A great sphere of usefulness would be the continued care of pa

tients who have gone through the acute phase of intercostal paralysis due to poliomyelitis and who continue to have some residual degree of paralysis

5 ELECTROPHRENIC RESPIRATION (E P R)

Electrical stimulation of the phrenic nerve to create diaphragmatic contraction and thus a respiratory effort had been recom

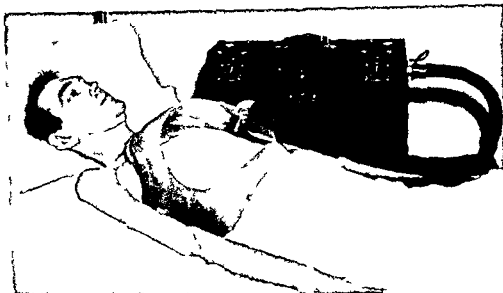


Figure 107 Chest model respirator

mended as far back as 1881 (266) Sarnoff *et al* (328 329 330) and Whittenberger *et al* (391) in recent times have succeeded in demonstrating the effectiveness of this method The type of respiration produced by artificially causing the diaphragm to contract is more nearly physiologic than that produced by the intermittent positive pressure breathing apparatus Such respiration if properly induced and maintained avoids the adverse circulatory effects of the elevated intrapulmonary pressures common to the use of the intermittent positive pressure breathing methods

Sarnoff developed an apparatus (Figure 108) for this purpose By the use of a Grass stimulator and a rotating potentiometer electrical impulses at 40 per second with a duration of two milliseconds each are applied over the phrenic nerve With each surge of impulses the diaphragm contracts It contracts smoothly and its action resembles that seen during spontaneous respiration The

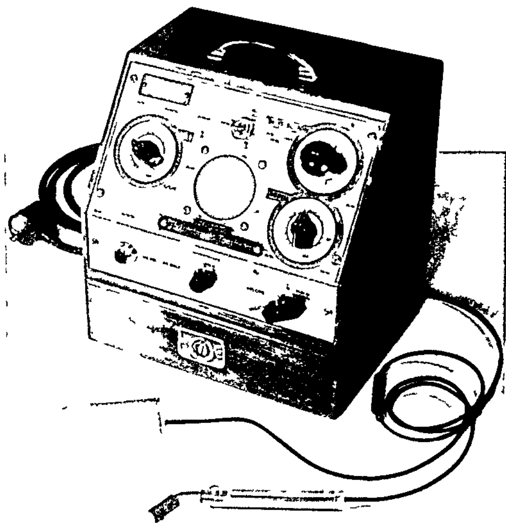


Figure 108. Electrophrenic respirator (E.I.R.)

degree of contraction controls the amount of ventilation and is directly proportional to the peak voltage applied. By such means normal minute volume exchange, arterial blood oxygen and blood carbon dioxide tensions of both the experimental animal and man can be duplicated with sub maximal stimulation of one phrenic nerve in the absence of spontaneous respiration. Maximal stimulation of one phrenic nerve can produce overventilation and thus an alkalosis. With bilateral maximal phrenic nerve stimulation one can produce a further decrease in arterial carbon dioxide blood tension and can triple the animal's spontaneous minute volume.

Even in the presence of spontaneous breathing electrophrenic stimulation can take over respiration with a cessation of such spontaneous efforts This inhibition has two components The first is due to the fact that a sustained diaphragmatic contraction reflexly inhibits respiration The second component is inhibition of spontaneous respiration because of the change in blood chemistry brought about by electrophrenic respiration Not only may the tidal volume and minute volume be regulated satisfactorily but the ratio of the length of inspiration to the length of the total cycle can be varied from 25 to 72 per cent The respiratory pattern can be regulated at will By prolonged experiments Sarnoff *et al* have shown that the neuromuscular mechanism is capable of sustaining prolonged electrical stimulation and thus the method is capable of maintaining artificial ventilation for long periods of time

The authors are convinced that the method has great potentiality because the apparatus is portable and of low cost A minimum of nursing care is required and there is maximum freedom of movement on the part of the patient Further there is the therapeutic effect of keeping a partially paralyzed diaphragm active Because the impulse descends through the phrenic nerve it can be employed only on patients whose phrenic nerves are intact as patients with bulbar depression or paralysis or patients with high spinal anesthesia

When first employed experimentally the electrode was placed directly on the exposed phrenic nerve As a result of continued experience with the apparatus one can now employ a fingertip electrode which can be placed directly over the phrenic nerve and the current passed through the intact skin to cause satisfactory ventilation The method has great value It is interesting to see how great is the control over respiration even through the contraction of but one side of the diaphragm The ventilation produced can be made fully equal to that of normal respiration It is a piece of equipment that those who are called upon to ventilate patients should keep at hand for it has two unquestioned advantages First its great portability and second its production of nearly normal physiologic respiration

With the use of the E P R apparatus one should be especially

careful to remove any possible obstruction to respiration Increased diaphragmatic descent produced by the use of the E P R will if there is interference to the ingress of air produce a very marked intrapulmonary negative pressure Under such circumstances pulmonary edema may be developed

DISCUSSION

Artificial respiration has been repeatedly shown to be effective and life saving Such ventilation, in the presence of adequate circulation can be maintained for long periods of time with assurance that if the respiratory mechanism is viable a favorable result may be expected This assurance is repeatedly demonstrated in the operating room The well trained anesthesiologist does not hesitate to render the patient completely apneic and to actively breathe for the patient when such a course is indicated Success depends upon making certain that there is no serious depression of respiration until ventilation is adequately maintained There can be thus no delay in guaranteeing the patient a sufficient volume of air or oxygen to his pulmonary tree Whenever an individual cannot adequately ventilate himself ventilation should be immediately instituted by some one present and the means employed should be those which are at hand

The anesthesiologist knows that attempts at resuscitation are doomed to failure if the airway is inadequate Oral nasal or endotracheal airways are commonly employed The one responsible for carrying out artificial respiration must maintain a clear passage for air If no airways are available the tongue may be pulled forward with the patient prone or on his side If he is supine the tongue may be pulled out or the angle of the jaw pushed forward

In the operating room the patient s entire needs are cared for Undue heat loss is prevented and fluids are administered intravenously By the same token an accident victim on the beach or street should be cared for He should be kept warm and dry He should be handled gently Resuscitative efforts should not be traumatic If the patient is making respiratory efforts these should be aided Resuscitative maneuvers should be synchronized if possible with the patient s own efforts

So many means and methods for ventilation have been advo

cated that one may have difficulty in deciding upon the proper procedure It is the author s feeling that Red Cross workers fire men, and life saving guards at beaches should be taught and en couraged to use the Beecher modification of the Silvester method (page 237) or the hip rolling method of Thompson Girdlestone (page 242) If rescue teams can carry with them an apparatus to deliver oxygen the two methods can be used together Such oxy gen delivery apparatus inhalators do not attempt to force the patient to breathe Respiration is performed by the manual method above described When inhalators are used the gas ad ministered should be 100 per cent oxygen Carbon dioxide to re peat has no place in artificial respiration

Rather than placing dependence upon any of the automatic cycling devices for field use my personal preference would be for the hand bellows type of respirator as recommended by Kreisel man This has been recently improved by the placement of a flange to prevent interference with the valve action This apparatus is small readily transportable and is of low cost Rescue workers can be taught to use this simple apparatus in a very short time—in less time in fact than it takes to teach any of the manual methods of artificial respiration In the box carrying the apparatus are air ways which should be used The respirators are inexpensive enough to be sown around in areas where they may be needed They should be kept at rescue stations and carried in ambulances

In hospitals respiratory accidents often occur in operating rooms Here the greatest reliance should be placed upon the mod ern gas machine It is one piece of apparatus which should always be in functioning order There should always be a cylinder of oxy gen on it which has not yet been opened Airways and endotracheal tubes are immediately available and should be employed

Emergency units containing the equipment for immediate use in resuscitation should be kept in strategic areas throughout a hos pital In each of these units should be kept a Kreiselman bellows respirator various sized airways—oral nasopharyngeal and endo tracheal—and a laryngoscope with adapters to fit the endotracheal tubes to the Kreiselman apparatus

Respiration can be instituted with the above equipment If *arti ficial* respiration is needed over a prolonged period of time the

patient can be transported with the apparatus still in use to a Drinker type respirator Respiration can be maintained while the patient is placed in this apparatus The Kreiselman apparatus may momentarily be discontinued while the patient s head is drawn through the rubber collar Respiration can be maintained by the use of the Kreiselman apparatus until the Drinker apparatus is started and is properly functioning

The problem of infant resuscitation is sufficiently important to be handled by itself and will be considered in the section on Asphyxia Neonatorum

E ASPHYXIA NEONATORUM

The need for ventilatory resuscitation cannot always be anticipated Accidents may occur in homes on the street and in places where there may be no special equipment available and where there may be no trained personnel to employ it In hazardous areas where accidents may be anticipated as bathing beaches swimming pools and at fires there has been some attempt made to have equipment and personnel available to carry out ventilatory resuscitation The number of accidents which may occur in such areas though large however does not begin to compare in number with the situations which call for resuscitation in delivery rooms Eastman and Kreiselman (136) state that the number of babies that die at birth in the United States approximates 80 000 annually Since an additional 30 000 die during the first day of life from causes which are almost all natal in origin the total infant mortality consequent upon a change from intra to extra uterine life is about 110 000 yearly Approximately 4 per cent of all fetuses and newborn children reaching a size and development compatible with extrauterine existence die before during or soon after birth (274) In spite of the fact that there has been a steady improvement in neonatal mortality during the past 20 years there has been almost no decrease in the deaths during the first 24 hours after birth (132)

There is almost unanimity that many of the deaths within 24 hours are due to hypoxia of the fetus (136 271 398) It is also apparent that many of the physical and mental aberrations of later life are due to the same cause Biggs (66) states A large portion of mental and motor impairment in later life is due to insufficient

oxygenation of the brain immediately after birth Windle (398) believes that there is reason to suspect that many spastic children are so because of brain damage from oxygen want during labor and birth Windle feels also that although some individuals may escape clearly defined or persisting symptoms of organic neurologic damage, they may indeed suffer from impairment of mental functions Too many are content to assume that a significant percentage of the population is born defective mentally when clinical evidence suggests a close relationship between oxygen deprivation at birth and later neurological defects Windle determined experimentally the effect of oxygen deprivation on animals Using controls and litters of two or more offspring one fetus was delivered by section before asphyxiation of the remainder by clamping the uterine or the umbilical vessels The fetus delivered first served as a control After cessation of intrauterine respiration one or two fetuses were delivered and resuscitated by various means The duration of the periods of oxygen deprivation varied from 4½ minutes to 23 minutes Resuscitation required various intervals but varied in proportion to the duration of oxygen deprivation His topathological studies were made in 80 brains of asphyxiated animals and 60 of the normal controls All experimental animals that were rendered hypoxic exhibited symptoms of a neurological nature after birth Generally the more prolonged the oxygen deprivation the more marked were the signs of central nervous system involvement There were however instances of marked impairment of nervous functions after brief oxygen deprivation and slight impairment after very prolonged hypoxia Some animals died after resuscitation In these animals were found hemorrhages in the medulla oblongata in the region of the respiratory centers Others who lived for a day or more showed marked motor disturbances Those that survived were killed for histopathologic studies This latter group showed a very great variety of neurological symptoms Brain pathology was found in nearly all animals that had been rendered hypoxic for eight minutes or more Animals which had been rendered hypoxic at birth and which survived four to eight weeks were together with their normal litter mates subjected to tests for their ability to learn a simple alternation type of maze problem The normal animals or those which were not rendered

hypoxic learned this problem promptly and easily At the conclusion *of the tests all animals were killed for histologic studies of the* brain Forty eight had been asphyxiated during birth and 40 had not been Thirty one of the experimental animals showed structural brain changes attributed to hypoxia Of these 31 27 were inferior to the litter mate controls in learning the maze problem Windle showed clearly that oxygen deprivation at birth had produced changes in brain function as well as in its structure Windle concludes his essay with the following statement We are prone to blame inferior human mentalities on poor environment or defects in the germ plasm Can it be that asphyxia at birth is partly responsible?

In the normal fetus there are several mechanisms which insure an adequate oxygen supply, for the oxygen capacity of fetal blood is greater than that of the mother in the later stages of gestation At the time of birth the oxygen capacity of blood in the umbilical vein is about 21 5 volumes per cent Windle notes however that there is one factor which tends to impair the efficiency of oxygen of the newborn infant s blood and especially that of the premature infant There is a deficiency in the newborn of the enzyme carbonic anhydrase which accelerates the release of carbon dioxide in the lung The amount present in the newborn is less than one half that in the adult blood Under normal conditions the oxygen available to the fetus appears to be more than adequate to meet his needs if the advent of birth is not long delayed The reservoir of oxygen is about 40 cubic centimeters If oxygen deprivation occurs the fetus can survive for a period beyond that in which the blood oxygen is gone Animal experimentation by Himwich *et al* (221) has shown that survival time of a newborn rat during complete oxygen deprivation is about 50 minutes compared with the adult survival time of 3 minutes By preventing the newborn fetus from utilizing his blood sugar the survival time is made to approach that of the adult It would thus seem that anaerobic glycolysis is a device aiding the survival of the newborn

The fetus is capable of performing respiratory movements at an early age Whether any fetus normally exercises its respiratory mechanism in utero is unknown Rosenfeld and Snyder (314) believe that active respiratory movements occur throughout a large

part of intrauterine life The administration of carbon dioxide oxygen mixtures or interference with oxygen supply to the maternal animal will cause the fetus in utero to respond to such stimulation by respiration Windle (398) has shown that there are two types of respiratory movements which may be observed experimentally Weak movements produce no aspiration of amniotic fluid but if the oxygen deprivation to the maternal animal is great a marked stimulation of respiratory movement occurs with aspiration of amniotic fluid into the pulmonary tree Studies with radiopaque material show that hypoxic animals aspirated sufficient amniotic fluid to fill their lungs Davis and Potter (116) suggest that aspiration of amniotic fluid may be a normal phenomenon Windle and Becker (399) question the adequacy of their controls It is Windle s contention that aspiration of amniotic fluid is not a normal phenomenon but occurs under conditions of asphyxia Fortunately for the fetus a wide margin of safety is provided against the danger of drowning in its amniotic fluid Rosenfeld and Snyder (314) have shown that with continued oxygen deprivation to the maternal animal respiratory movements cease

Respiration begins at birth because of increased sensitivity of the respiratory center from hypoxia the result of placental separation plus the effect of afferent external stimuli from a change in environment If the respiratory center has been rendered less sensitive because of advanced oxygen deprivation or because of the effect of narcotics and anesthetics regular respiration will not be initiated

ETIOLOGY OF FETAL DEATHS

Death of the newborn is attributable to factors which occur during the intrauterine the intrapartum or the neonatal period Of the fetuses which perish before birth it is said that one fourth show evidence of oxygen want (274) Oxygen deprivation may have been due to such factors as partial separation of the placenta maternal pneumonia cardiac decompensation anemia or pituitrin stimulation Because of the hazard of oxygen deprivation to the fetus one must not neglect the danger of high altitude flying by the pregnant mother The cause of oxygen paucity during the intrapartum period may be the result of obstetrical factors—compres

sion of cord operative procedures, or anesthesia In the neonatal period death may be due to these factors continuing on to death of the newborn Almost one half of the total fetal wastage occurs after birth, although the genesis for most of these deaths occurs during labor (274)

Biggs (66) divides the factors which may be responsible for the death of the newborn into anatomic obstetric and physiopathologic Under anatomic factors he lists malformation of the circulatory and respiratory organs diaphragmatic hernia hypoplasia of the mandible and abnormal mobility of the tongue Under obstetric factors he states The preponderance of the opinion of the most careful observers indicates that the incidence and severity of asphyxia neonatorum is directly proportional to the amount of operative work done, also that it is directly proportional to the amount of anesthesia used in delivery and to the amount of narcotics given to the mother a short time before delivery Under physiopathologic factors one must consider prematurity intracranial hemorrhage prolonged labor and compression of the cord

ROLE OF ANESTHESIA AND SEDATION

Henderson (206) stated More or less prolonged apnea appears in 30 per cent to 60 per cent of babies born to mothers who have received narcotics in order to soften the curse of Eve Pharmacologists and anesthetists agree with Beck (53) that most of the methods which have been recommended for the relief of pain during labor may cause the death of the child if they are not given with caution With the possible exception of alcohol apomorphine and scopolamine all the agents employed for sedation are respiratory depressants All the general anesthetic agents also will produce depression of the mother s respiration It is important to note that the fetal respiratory system during intrauterine life is peculiarly sensitive to narcosis and the reaction to a particular anesthetic cannot be predicted from the response of the maternal animal (314) In fact the fetal respiratory system seems to be more sensitive than that of the mother to the depressant action of anesthetics and narcotics It is then because of the use of analgesics and sedatives for pain relief that we face the great problem of oxygen

deprivation in the fetus Such drugs increase the hypoxia of the newborn in direct proportion to the amounts given (95)

The barbiturates have long been commonly employed for pain relief The barbiturates are not analgesics In order to obtain the effect which many obstetricians promise their patients— You will not know anything about it —it is necessary to use these drugs in too large doses The barbiturates are powerful respiratory depressants It is this class of drugs which has been more responsible than any other single group for the high morbidity of the newborn It is true that while under barbiturate medication the mother may react to pain and may thrash about and moan with respirations not seemingly depressed but careful observation between labor pains will however, reveal that respiration may indeed be very much depressed

Nitrous oxide oxygen, in concentrations sufficient for operative obstetrics occasionally reduces the oxygen content of the umbilical blood to extremely low levels (134) Because of this it has been recommended that at no time should nitrous oxide be given with less than 20 per cent oxygen concentration in the inhaled atmosphere and that this mixture should be given in sufficient volume It has been found however that nitrous oxide oxygen even in 80–20 mixtures will produce definite maternal and fetal hypoxia (359)

Ether carefully administered will not interfere with oxygen availability It must be noted however that following its administration there is often a very long period of depression for it is necessary that the fetus eliminate this drug

Cyclopropane oxygen Under this anesthesia the blood of the infants is better oxygenated than under nitrous oxide oxygen (359) With cyclopropane anesthesia the youngster can desaturate rapidly

Rosenfeld and Snyder (314) evaluated the anesthetic agents by determining their effect on fetal respiratory movements They found that pentobarbital sodium paraldehyde chloral hydrate and morphine had caused a striking depressant action The volatile agents—nitrous oxide and oxygen—had no effect if the oxygen percentage in the inhaled mixture was satisfactory However if there was an insufficient amount of oxygen breathed there was

definite hypoxia and respiratory depression These authors also found that ether caused a marked depression by the time surgical anesthesia of the maternal animal was reached Cyclopropane oxygen they determined even with full surgical anesthesia had no depressant action on the fetus They conclude Because of the peculiar sensitivity of the fetal respiratory system to depression by anesthetics the fact of anesthesia must be regarded as an important one in the pathogenesis of respiratory failure at birth

The use of nerve block technics epidural, caudal and spinal anesthesia for deliveries has revealed how promptly and effectively the newborn will breathe if his respiratory center has not been depressed by the analgesics and anesthetic agents mentioned above The proper use of these latter methods will undoubtedly lead to a marked improvement in neonatal morbidity The use of the regional epidural caudal and spinal anesthesia technics however is not without danger In themselves these procedures may produce oxygen want in the mother and thus in the unborn fetus Epidural and spinal anesthesia may cause intercostal paralysis The regional technics may because of idiosyncrasy to the anesthetic agent or because of overdosage produce convulsions In careful hands the dangers in these procedures can be kept sufficiently low as to make the technics practical

To decrease the morbidity of oxygen want in the newborn one must anticipate its occurrence Better obstetrics is but part of the picture Improved anesthesia and better attention to the mother is a great part of the problem Any occurrences of fetal bradycardia must be interpreted as a possible response to hypoxia It has long been demonstrated that administration of oxygen to the mother between contractions will correct to a large degree the bradycardia of the fetus during labor pains (46 263 387) This simple therapy should be instituted in situations in which neonatal mortality is especially high that is prematurity multiple births and toxemias of pregnancy In the administration of the anesthesia the skill and judgment of the anesthetist is of paramount importance The obstetrical floor is usually at some distance from the operating room Too often obstetrical anesthesia is relegated to the newer nurse technicians Supervision of anesthesia on the obstetrical floor approximating that in the operating room is long overdue In

many ways anesthesia of the obstetrical patient is more difficult than that of the patient who comes to the operating room The patients who come to the operating room are usually well prepared Too often mothers come to delivery with full stomachs In obstetrics the anesthetist assumes the responsibility for the oxygenation of two individuals the mother and the child The obstetrical patient is often not cooperative and may be more difficult to handle Very few delivery rooms in this country are adequately supplied with proper gas machines oral airways endotracheal airways suction apparatus laryngoscopes bronchoscopes etc Too few of the mothers in labor receive adequate fluid therapy Blood administration is too often delayed To correct this state of affairs there should be increased cooperation between the departments of obstetrics anesthesia and pediatrics

ROLE OF RESUSCITATION IN ASPHYXIA NEONATORUM

Slapping thumping tubbing and swinging the newborn child is traumatic Trauma has no place in resuscitation The same principles hold true for infant as for adult resuscitation Respiratory stimulants as noted in the section on resuscitation have no place in this endeavor Carbon dioxide as a respiratory stimulant is fully as hazardous for the newborn as it is for the adult The reader is referred to the previous section on Carbon Dioxide and to the work of Eastman and Kreiselman in this regard As the administration of anesthesia has often been relegated to the poorest of the nurse technicians or to the internes so has the resuscitative endeavor been the lot of the junior member of the obstetrical team Very rarely is this individual instructed in the proper means of effecting ventilatory resuscitation The use of respiratory stimulants carbon dioxide inadequate or improper resuscitative methods not only does no good but indeed may do harm The role of ventilatory resuscitation in the newborn is like that of the adult—the administration of oxygen creation of a satisfactory tidal exchange and elimination of carbon dioxide

RESUSCITATIVE PROCEDURE

The procedure to be employed depends upon the status of the newborn baby Under all circumstances the pharynx should be

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there is no store of gas in the system The constant application of the Miller Mask will not only interfere with the youngster taking a breath on his own but will adversely affect circulation because of continued intrapulmonary positive pressure

The Kreiselman Infant Resuscitator (Figure 89) will produce intermittent positive pressure in a proper pressure curve relationship and does not interfere with the baby's breathing on his own



Figure 109 Kreiselman tube for infant endotracheal oxygen insufflation

for it serves as both a respirator and an inhalator The pressure employed is readily controllable

When endotracheal insufflation is necessary the trachea should be gently aspirated with electrical suction through a soft catheter An endotracheal tube is then passed which should be of rubber and shaped as is the Kreiselman tube (Figure 109) As noted from the figure there is an acute increase in the diameter of the tube so that the tube cannot be inserted beyond this point and thus damage is prevented The proximal end of the tube should be connected to an apparatus such as the Kreiselman Infant Resuscitator for intermittent insufflation of oxygen Flagg recommends the use of a right angle shaped apparatus as in Figure 110 for endotracheal insufflation The point at which the diameter of the apparatus increases is to be placed down upon the cords It limits the extent to which the apparatus enters the trachea The apparatus functions well The single hazard is that the tip is metal and rather sharp pointed Unless the instrument is passed with the head fully extended it is possible that the metal tip will impinge upon the posterior wall of the trachea and there cause damage

A Drinker type apparatus has been especially designed for the newborn There seems to be a swinging away from this type of apparatus (66) If it is available one should not hesitate to employ it

aspirated by some gentle means Postural drainage by the obstetrician for a short period of time is indicated The youngster should be placed on a warm platform with head slightly dependent and extended Aspiration of the mouth and pharynx through a catheter by mouth suction is not always satisfactory It is recommended that mechanical suction be employed and the degree of negative pressure be adequately controlled If the newborn is but mildly depressed and is moderately active simple aspiration of mucus and amniotic fluid usually suffices If the newborn is moderately depressed with decreased muscle tonus and offers no resistance to opening of his mouth oxygen should be applied by some simple means If respiration does not take place within a minute or two very careful direct laryngoscopy should be performed If the cords are in medioduction or if the patient reacts to laryngoscopy, the laryngoscope should be removed and oxygen again applied to the face If the cords are in lateroduction the trachea should be gently aspirated by catheter or by rigid tube The rigid tube is more easily inserted than is the catheter Care should be taken when inserting this tube for the distance between the glottis and the bifurcation is less than two inches If the newborn makes no respiratory movement or does not react then oxygen under controlled pressure should be insufflated intermittently If the respiratory depression has been due to hypoxia and this hypoxia has not been too long protracted the youngster will begin to breathe spasmodically at first and then regularly He will continue to show improvement If the respiratory depression is the result of continued effect of the anesthetic agent administered to the mother then some means must be at hand to maintain respiration until the youngster can eliminate the drug which he has received through the placenta

APPARATUS

Here too as for adult resuscitation intermittent positive pressure breathing is the most dependable Intermittent positive pressure breathing may be instituted by the Miller apparatus in which the compressed gases are delivered through a face piece The amount of pressure delivered is controlled by a steel ball resting on a seat This apparatus is effective in producing inspiration The mask should however be intermittently applied and removed, for

Gellis *et al* postulated that the fetus swallowed amniotic fluid which was later regurgitated and aspirated Gastric suction revealed that the stomachs of infants of diabetic mothers delivered by caesarean section contained an average of 20 cubic centimeters and the stomachs of infants born by caesarean section of non diabetic mothers yielded an average of 14 cubic centimeters Aspiration of stomachs of infants delivered by low forceps gave but two cubic centimeters It is thus possible that regurgitation and aspiration may account for the appearance of the delayed hypoxia Gellis *et al* state The increased amount of fluid in the upper respiratory tract of these infants must necessarily be inhaled with the first breath unless removed by the physician Aspirated material at first lies loosely distributed in the alveolar spaces but each successive breath packs the debris against the alveolar walls forming the asphyxial membrane composed of amniotic detritus meconium lanugo and vernix Delayed respiratory obstruction is dependent upon an increasingly impervious alveolar membrane

Of 25 infants who received gastric suction at birth by these authors four showed respiratory embarrassment that was present at birth and none developed respiratory difficulty Of 25 infants in whom suction was not performed 15 developed respiratory difficulty In six it was present at birth but nine of the 15 showed a delayed onset of obstructive signs Because of the above findings it is recommended that gastric suction at birth be carried out in infants delivered by caesarean section

TECHNIC OF SUCTION

Within one or two minutes after the extraction of the infant oxygen is administered and gastric suction carried out by means of a #10 French catheter passed through the oropharynx The catheter connected to a suction apparatus is slowly passed down the mouth into the esophagus with constant suction applied and with slow rotating movements of the catheter between the fingers When the catheter reaches the stomach gentle pressure is applied on the abdomen to facilitate the greatest yield of fluid The catheter is withdrawn slowly with suction still applied Oxygen is then administered for approximately one or two minutes after which time the gastric aspiration is again performed This procedure is re

when a long period of artificial ventilation is required to maintain the oxygen supply to an infant who has been depressed because of narcotics and anesthetics

Here one should not overlook the possibility that the electro phrenic respirator of Sarnoff might be of value As previously stated it is designed to produce diaphragmatic contraction The respiration it produces is more nearly physiologic than any other

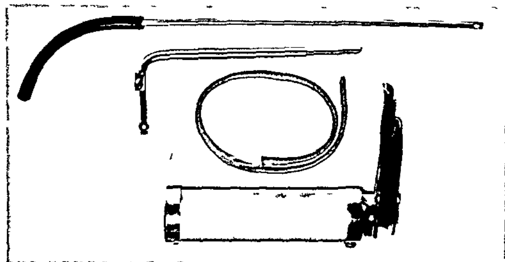


Figure 110 Infant laryngoscope catheter for pharyngeal aspiration right angled Flagg apparatus for endotracheal insufflation endotracheal aspirator tip

forms of resuscitation we have mentioned Adequately and care fully handled it should be of value

ROLE OF GASTRIC SUCTION

It had been noted by Gellis *et al* (171) that infants born to diabetic mothers delivered by caesarean section were prone to de velop severe hypoxia either immediately or several hours after birth It is agreed that the incidence of respiratory difficulty and the mortality rate are higher in infants born by caesarean section than those delivered through the pelvis for delivery by caesarean section increases the likelihood of aspiration of amniotic fluid Such aspiration may explain the immediate respiratory distress but does not explain the occurrence of obstructive hypoxia which may be seen several hours later

pulsation is lost Others (54) agree that when epinephrine is employed in the presence of asystole the heart may indeed start beating but instead of the rhythm being normal the ventricles may be thrown into fibrillation Epinephrine, however is recommended as of value under certain circumstances (55 322)

The needling of the heart for the purpose of introducing epinephrine is said to be harmful of itself Such an injection wounds the heart and produces a small area of myocardial damage which may lead to the development of what is termed an injury current (226) Such trauma if instituted very soon after the heart has stopped may generate an ectopic beat in the heart muscle with favorable results If such a procedure is not instituted within 90 seconds however the threshold for stimulation is increased and the ectopic beat when produced will be followed by a series of extrasystoles with failure of the normal pacemaker to be followed by fibrillation Since auricular fibrillation is more compatible with life than is ventricular fibrillation and since the auricles are more sensitive to mechanical stimulation all intracardiac injections should be by way of the auricles

It is generally agreed that attempts to revivify a heart which is fibrillating or asystolic should be more direct Cardiac compression now stands as the procedure more likely to result favorably than any of the above alone Regardless of the procedure employed it is absolutely necessary that efforts at cardiac resuscitation should be accompanied by efforts to improve and maintain good pulmonary ventilation preferably with high oxygen concentrations in the breathed atmosphere

As previously stated manipulation of the heart itself may cause fibrillation or asystole Beck and Mautz (54) feel that this may be the result of exposure manipulation or surface stimulation of the heart Simple exposure of the heart may result disastrously because of a change from the subatmospheric pressure which normally surrounds it to atmospheric pressure This may be the final straw that stops the heart Manipulation such as local pressure angulation of the heart from its normal axis and torsion on its long axis may also have deleterious effects Simple surface stimulation may also result disastrously

Beck and Mautz (54) describe the methods for control of such

peated two or three times until fluid from the stomach can no longer be obtained It is then wise to place the infants in an oxygen atmosphere and suction of the nares nasopharynx mouth and oropharynx should be carried out at three hour intervals

II CARDIAC RESUSCITATION

The very great majority of instances of cardiac cessation are not remediable because of the disease processes underlying their production It is however apparent that cardiac standstill under certain circumstances can be reversed with survival (242, 322, 373 378) The heart will respond by fibrillation or standstill to certain forms of insult which may occur during anesthesia and surgery This condition is said to occur in a busy operating room about twice a year (18, 322)

Increased sensitization of the heart to epinephrine by the anesthetic agents chloroform ethyl chloride and cyclopropane may precipitate this emergency Hypoxia not only increases myocardial sensitivity to epinephrine but increases its production Parasympathetic stimulation by the barbiturates and cyclopropane may inhibit cardiac activity Reflex vagal effects due to surgical manipulation may produce cardiac standstill

In contrast with the resuscitative interval in acute deprivation of oxygen by inefficient ventilation the resuscitative interval of acute cardiac fibrillation or asystole is exceedingly small It behooves those who are responsible for the care of patients during anesthesia and surgery to recognize the catastrophe readily and to be prepared to handle it effectively

Efforts to revivify the heart in asystole have been many and varied Pressure on the thoracic cage thumping the area over the precordium needling the heart and the intracardiac injection of drugs have been reported Hyman (226) describes a technic for the introduction of drugs into the right auricle through the intact chest wall and for years epinephrine was so employed Drinker (129) states There is no practical procedure which affects the fibrillating heart muscles and an intracardiac injection of epinephrine can be relied on to do but one thing namely make fibrillation worse so that any chance of spontaneous shift to normal

successfully defibrillated the ventricles in the human heart in two patients both of whom recovered

Cardiac standstill or fibrillation may occur in the operating room when the chest has not been entered Here too, cardiac compression is indicated Various approaches for this have been advocated These may be divided into three groups (1) transperitoneal and subdiaphragmatic (2) transperitoneal transdiaphragmatic and (3) transthoracic The transthoracic is the most direct and most satisfactory route The approach should be made quickly through a transverse incision in the left third or fourth interspace The ribs should be widely retracted and with the heart under direct vision cardiac compression should be applied at the rate of about 50 per minute Warm saline solution should be poured over the heart at frequent intervals to prevent dehydration The effectiveness of such cardiac massage was demonstrated by Gunn (188) He showed that a dye injected into the right ventricle of a heart which has ceased beating appeared in the lungs and carotid artery after but a few compressions of the heart

Burstein (84) demonstrated the successful use of procaine intravenously in patients who have developed cardiac arrhythmias during operative procedures within the thoracic cage Procaine as previously stated has been shown to be effective in the treatment of ventricular fibrillation Ruzicka and Nicholson (322) combined procaine and epinephrine intravenously or intracardially They administer 0 5 cubic centimeters of epinephrine and 9 5 cubic centimeters of 1 per cent procaine Although there is very serious question about the use of epinephrine most of the authorities recommend repeated use of procaine should it be indicated

There have been sufficient complete recoveries by cardiac compression to require that every operating room should be thoroughly equipped to handle this emergency There should always be available in the operating room the proper instruments to enter into the thoracic cage separate the ribs and expose the heart so that cardiac compression can be done in the shortest possible interval after cessation of cardiac action

After re establishment of the heartbeat any one of three things may result There may be complete recovery of the heartbeat

fibrillation Physiologists (223 392) have contributed two methods for defibrillation of the ventricle One is to bring the heart to a complete and absolute standstill by a solution of potassium chloride and then to restore its action by solutions of calcium chloride The authors feel that the potassium calcium method was superseded by sending an electrical current through the ventricles stopping fibrillation and then restoring the normal rhythm by intermittent compression This method was described in 1899 by Prevost and Battelli (305) In defibrillation of the heart Beck and Mautz (51) maintain adequate aeration of the lungs expose the heart and massage the ventricles about 50 times a minute An electrode is then placed on each side of the heart and an electric current is run through the ventricles The current is ordinary current of 60 cycles and of 1 to 1 5 amperes Its application is short from 0 5 to 2 0 seconds If such procedure fails to stop the fibrillation procaine is indicated They applied two cubic centimeters of 5 per cent procaine upon the auricles and ventricles with continuation of massage Every vestige of fibrillary movement must disappear before there is any hope of success

Beck and Rand (55) stress the fact that there is no urgency in restoring the heartbeat If the ventilation of the lungs is adequate preferably through an endotracheal tube and if the heart is slowly compressed the urgency for the restoration of the beat is not great When the heart stops it is either in ventricular standstill or ventricular fibrillation It is sometimes extremely difficult to distinguish one from the other The treatment for each is different however Because from the standpoint of treatment it is important to distinguish between them *an electrocardiogram is advisable* and time can be taken for this Massage alone may correct ventricular standstill or asystole If cardiac compression alone fails Beck and Rand feel that epinephrine may then be used They employ 0 5 cubic centimeters of a 1 1000 epinephrine solution diluted in 5 cubic centimeters of sodium chloride In the presence of ventricular fibrillation they employ 5 cubic centimeters of 1 per cent procaine solution part of which is applied to the surface and the remainder of which is injected into the right ventricle These authors too employ electric shock to defibrillate the heart They have

successfully defibrillated the ventricles in the human heart in two patients both of whom recovered

Cardiac standstill or fibrillation may occur in the operating room when the chest has not been entered Here too cardiac compression is indicated Various approaches for this have been advocated These may be divided into three groups (1) transperitoneal and subdiaphragmatic (2) transperitoneal transdiaphragmatic and (3) transthoracic The transthoracic is the most direct and most satisfactory route The approach should be made quickly through a transverse incision in the left third or fourth interspace The ribs should be widely retracted and with the heart under direct vision cardiac compression should be applied at the rate of about 30 per minute Warm saline solution should be poured over the heart at frequent intervals to prevent dehydration The effectiveness of such cardiac massage was demonstrated by Gunn (188) He showed that a dye injected into the right ventricle of a heart which has ceased beating appeared in the lungs and carotid artery after but a few compressions of the heart

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After re establishment of the heartbeat any one of three things may result There may be complete recovery of the heartbeat

respiration and cerebral function The heart may function properly respiration may be satisfactory, but because of advanced oxygen deprivation to the brain there may be altered cerebral function On occasion the heart may recover but respiration will not be resumed with ultimate death of the patient Often a patient may linger unconscious but breathing well with seemingly good heart action and die after a protracted period of one to fifteen days These patients exhibit the characteristic brain damage of cerebral hypoxia

A rather important detail to consider in the handling of these emergencies is another means to improve the state of myocardial oxygenation by increasing the head of pressure within the coronary vessels To accomplish this intra arterial transfusions are administered Negovsky (284) has shown in experiments on dogs that arterial infusion of blood plus epinephrine and glucose together with powerful artificial respiration constituted the most effective method of revival Hale (196) has demonstrated that the intra arterial injection of blood in a peripheral artery will cause a sufficient back pressure within the aorta to improve effectively the flow of blood into the coronaries and to the brain This procedure has been employed clinically for some time with extremely good results It has been employed particularly in the presence of acute falls in blood pressure because of hemorrhage or shock Since the method has been so satisfactory it would seem indicated in the presence of acute cardiac standstill because of the improved coronary and cerebral blood flow it provides

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